# ELEKTOR ELECTRONICS

THE INTERNATIONAL ELECTRONICS MAGAZINE
JANUARY 1992
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## Build a compact-disk player

**Windspeed and direction meter**
**PWM temperature controller**
**Low-frequency counter**
**Direct conversion radio**
**Mini Z-80 system**

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ELEKTOR ELECTRONICS

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January 1992
Volume 18
Number 196

***Front cover***
Building a record player, cassette or tape recorder, or compact-disk player, is often hampered by the mechanical construction and the availabity of certain parts, particularly the deck. In the past, manufacturers have generally tended to be reluctant to make tape or CD decks available to the retail trade, but Philips has recently decided to break away from this policy. A kit, containing its CDM-4 deck and associated mother board, can now be obtained from certain retailers at an affordable price.

We regret that owing to circumstances beyond our control, the article *'PWM temperature controller'* has had to be held over till the February issue.

**In next month's issue:**

Among others:
- Improving portable radio performance
- I2C interface for PCs
- Mini square-wave generator
- RAM extension for mini Z80 system
- Audio/video switching unit
- PWM temperature controller
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- Direct digital synthesis - DDS

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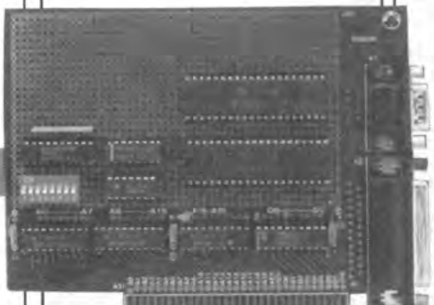

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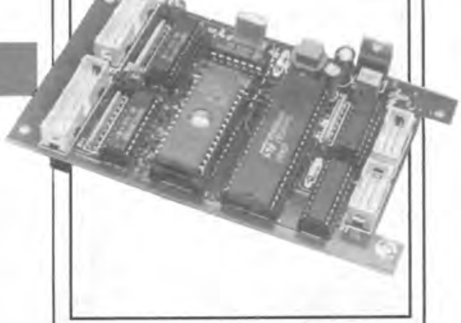

Mini Z80 system - p. 14

# ELECTRONICS SCENE

## MODERN MUSIC IS A 'DUET'

THE computer revolution in digital audio has created new possibilities for musical composition and research scarcely imagined a decade ago. The consequent demanding and rapidly developing field of modern electrophonic (electrosonic or electroacoustic) music calls for harmony between composer and sound engineer.

At York University in northern England, researchers have been involved in the development of a variety of systems geared to the requirements of modern composers. Understanding the fast pace of change in this field, the university has set up courses in 'music technology' that are designed to train musicians in new technological advances and to train electronic engineers in current musical thinking. The students are integrated throughout most of the course and form a new middle ground between the two main disciplines. Graduates are able to use their knowledge and skills in the recording industry, in sound production in radio and television, musical instrument technology and in composition of music. They may also become designers of studio and contemporary music systems.

Research by the university's music department has included 'the composer's desktop project', which originated in York but is now an international co-operative venture. It is a compact system that brings together sound-file, score generation and processing, graphical interfaces, in short, everything that is essential to today's composers.

Ambisonics, a British-designed method of coding and decoding spatial information concerning sound, is a major interest. Both the technology and compositional use of three-dimensional sound diffusion based on ambisonics are being studied. A programmable decoder, devised at the university, that can drive up to 16 loudspeakers in a three-dimensional array, has been used and appreciated in a variety of concerts, as well as for research into improved diffusion techniques. University of York, Music Department, Heslington, York YO1 5DD, England.

## SAFER LANDINGS WITH MICROWAVES

IN 1995, the Siemens Plessey Radar (SPR) P-SCAN 2000 microwave landing system (MLS) will come into use at London's Heathrow airport. This will represent a significant stage in the development of MLS, which is designed to meet the growing demand for precision landing guidance into the next century.

For many years, the instrument landing system (ILS) has been the standard approach and landing aid and has undergone development and refinement to enhance reliability and improve accuracy. Development has been such as to permit automatic landings to Category IIIb since the early 1970s. These conditions are defined as a precision instrument approach and landing with a decision height lower than 15 m, or no decision height; and a runway visual range less than 200 m, but not less than 50 m. Decision height in this context means a specified height in the precision approach at which a missed landing procedure must be initiated if the required visual reference to continue the approach has not been established.

**The azimuth equipment installed at London's Heathrow airport for the evaluation of the Siemens-Plessey microwave landing system.**

Despite the considerable progress achieved with ILS, it has become evident that it will not meet the operational needs in the future, and a search has, therefore, been proceeding for a better system. After lengthy consideration of various proposals worldwide, international agreement has been ob-

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tained to adopt the time reference scanning beam MLS and implement a transition plan to enable timely conversion of all ground and airborne installations from ILS to MLS.

Unlike ILS, MLS provides accurate guidance information over a wide azimuth sector up to ±40° from runway centre-line to a range of 18 km from threshold. Accurate elevation guidance is provided between +1° and +15°, which enables the use of steeper glidepaths. An additional back azimuth facility is also available for missed approach and departure guidance.

Two hundred channels are currently available in the 5030 MHz to 5090 MHz band, which overcomes ILS problems with frequency allocation. MLS operates on the time reference scanning beam principle, in which each radiating antenna (azimuth, elevation, back azimuth) forms a very narrow beam, which is scanned electronically, to and fro, at very high speed across the coverage sector.

The aircraft receiver detects the passing beams and measures the elapsed time between the 'to' and 'fro' beams, which gives a precise measurement of the angle of the aircraft relative to the zero degree runway-centreline reference, in the case of the azimuth antenna. In the same manner, the elevation system scans a beam up or down, and the back azimuth operates in a similar way to the forward or approach azimuth.

The complete system operates with time division multiplex, which means that each of the MLS functions (azimuth, elevation and back azimuth) is synchronized and takes its turn to radiate signals while the other transmitters remain silent.

The MLS antennas are very much smaller than their ILS counterparts as a result of the high frequency used. The antenna system is also independent of any ground effects and is highly immune to multipath effects because of the very narrow beamwidths that are used for microwave frequencies. MLS also offers considerable flexibility in the choice of approach path.

As part of the United Kingdom and international programme for MLS development and transition planning, a Plessey uncategorized system was installed at Heathrow in late 1986, following trials at Royal Aerospace Establishments. A second Plessey system was installed at Manchester in 1988, co-located with a newly installed ILS.

Siemens Plessey Radar Ltd, Oakcroft Road,
Chessington KT9 1QZ, England.

## ANALYSER III SPEEDS ACCURATE LINEAR CIRCUIT DESCRIPTION

Number One Systems' new software program, Analyser III, allows circuit designs to be tested and proved before a single component is soldered, thereby saving time and money as well as providing greater test accuracy. In many cases, the breadboarding stage can be eliminated completely, allowing prototypes to be built directly on the PCB.

Analyser III is claimed to be ideal for the analysis of filters, amplifiers, cross-over networks, wideband amplifiers, aerial matching networks, radio and TV IF amplifiers, crhoma filters, linear integrated circuit, and more.

Analyser III, which is not copy protected, costs £195, excl. VAT, complete with comprehensive manual, example circuit files and unlimited free telephone support.

Number One Systems Ltd, Harding Way,
Somersham Road, St Ives, Huntingdon
PE17 4WR, England. See also p.10.

## SAFETY WITH MAPLIN

NEW from Maplin are three safety products. The 'Street Alert' is a compact personal alarm with an extremely tough black plastic case. Because of its slim size, it can be carried easily by hand or be attached to a belt with the very rigid clip moulded into its housing.

A large pink button, recessed to prevent accidental operation, is pressed to operate an extremely powerful 130 dB siren guaranteed to draw attention to passers-by. The alarm is deactuated by simply pressing the button again. The alarm is powered by a 9 V PP3 (6F22) battery. (Our engineers have tested this unit and can vouch for the claims made by Maplin). At £19.95, incl. VAT, this is a most worthwhile protection unit for women on their own, school children, elderly citizens, and many more.

The 'Keypad Door Alarm' is versatile and easily fitted on the inside of a door. It comprises an attractive and robust main unit, fitted on the door itself, and a magnet assembly that is mounted on the frame.

When the door is closed, the magnet is detected by the proximity sensor within the alarm. When the door is opened, and the magnet moved away from the unit, the sensor detects the change and actuates a loud, piercing alarm. The alarm can be turned off only by entering a 3-digit code on the keypad found on the main unit.

There are four main modes of operation: visitors' chime; instant alarm; delay alarm; off (cannot be turned by simply selecting this switch). In addition, there is a red 'panic' button on the main unit that sets off the alarm instantly. Its price is £19.95, incl. VAT.

The "Photo/Video Flight' case is a high-quality ABS plastic instrument case designed for the safe and easy transport of cameras and portable video equipment. Solid foam provides protection from damage, while convoluted foam is fitted to the top lid to provide a wide surface for securing items of a complex shape.

The GL32K case is 380 mm long, 465 mm wide and 165 mm deep; it weighs 2.1 kg. It costs £34.95, incl. VAT.

Maplin Electronics PLC, P.O. Box 3,
Rayleigh SS6 8LR, England. Telephone
0702 552 911; fax 0702 553 935

## HENRY'S NEW 1991-92 CATALOGUE

THE NEW Henry's 300-page plus, colour catalogue is available by post (send C4 size with £2.65 stamps affixed for dispatch in Britain) or at £2.00 to callers at Henry's store in London. The catalogue comes with a retail/mail order price list, £90.00 worth of purchase voucers, and £2.00 off first purchase. There are also further supplements on test equipment, components and security.

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## NEW HQ FOR OKI EUROPE

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## ADVANCED DIGITAL LOGIC GUIDE

TEXAS Instrument has published a pocket booklet detailing its broad range of digital logic functions. It is intended as a tool that can assist engineers to keep pace with the rapid evolvement of new solutions in various applications.

Texas Instruments Ltd, Manton Lane, Bedford MK41 7PA, England.

### AN INTEGRATED SERVICE

An integrated service for the whole spectrum of electrical engineers will be provided by The Institution of Electrical Engineers (IEE) and The Institution of Electronics and Electrical Incorporated Engineers (IEEIE), following the signing of a Memorandum of Understanding by their presidents.

The IEE, with 110 000 members, will continue to be responsible for the needs of its chartered engineers and the IEEIE, with 28 000 members, for the needs of its incorporated engineers and technicians. The two institutions will collaborate in a number of activities, including accrediting academic and training courses, promoting careers in electrical and electronic engineering to young people, promoting joint technical meeting and providing a united voice to the Government and the the European Commission.

The IEE has already merged with the Institution of Electronic and Radio Engineers and is about to merge with the Institution of Manufacturing Engineers, while the IEEIE has already merged with the Society of Electronics and Radio Technicians. Both institutions are now the largest bodies in their respective fields who are nominated bodies of The Engineering Council.

The Memorandum of Understanding is a further drawing together of the institutions concerned with electrical and electronic engineering, computing, information technology and manufacturing engineering. It will strenghten the existing partnership for the benefit of members and the profession they serve.

IEE, Savoy Place, London WC2R 0BL.
IEEIE, Savoy Hill House, Savoy Hill, London WC2R 0BL.

### COMPACT LASER MODULES

Compact visible laser diode modules in the Imatronic range now have an added modulation option. Modulated versions offer 1–100 kHz modulation with a 1 μs rise time and can be driven from any TTL compatible source. These small modules make an ideal replacement for He:Ne lasers, offering the additional advantages of ruggedness and size.

Also, an infra-red (IR) version, operating at 820 nm and packaged in the same compact 49×16 mm housing, has been added to the range.

Units in both ranges include all the focusing optics and require 4–5.25 V to drive them.

Lambda Photometrics Ltd, Lambda House, Batford Mill, Harpended AL5 5BZ, England.

### AVANTEK PRODUCT SELECTION GUIDE

Avantek's 48-page *Product Selection Guide* is designed to provide the engineer with a quick overview of the company's standard products. For a free copy, contact your nearest Avantek regional office: in Britain, phone 0276 685 753.

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Gardners, Somerford Road, Christchurch BH23 3PN, England. Phone 0202 482 284.

### LEVELL ELECTRONICS ALIVE AND WELL

After joining the AET Group 15 months ago, Levell Electronics are now operating from their new site in Hertford. If you have lost track of them, you can keep up to date with their new and existing products by requesting their updated 6-page shortform brochure. The new brochure shows their range of test and measurement equipment for a wide range of markets, including avionics, audio and hi-fi, electronics, and research and educational establishments.

Levell Electronics Ltd, Technology House, Mead Lane, Hertford SG13 7AW. Telephone 0992 501 231; fax 0992 500 028.

### ALPHA SOFTWARE OPENS OFFICE IN UNITED KINGDOM

Alpha Software Corporation, the Burlington, Massachuchetts-based developer and publisher of PC software for business users, has opened an office in Plymouth. The new office will provide a full range of sales and support services to its British distributors, resellers, corporate clients and end users.

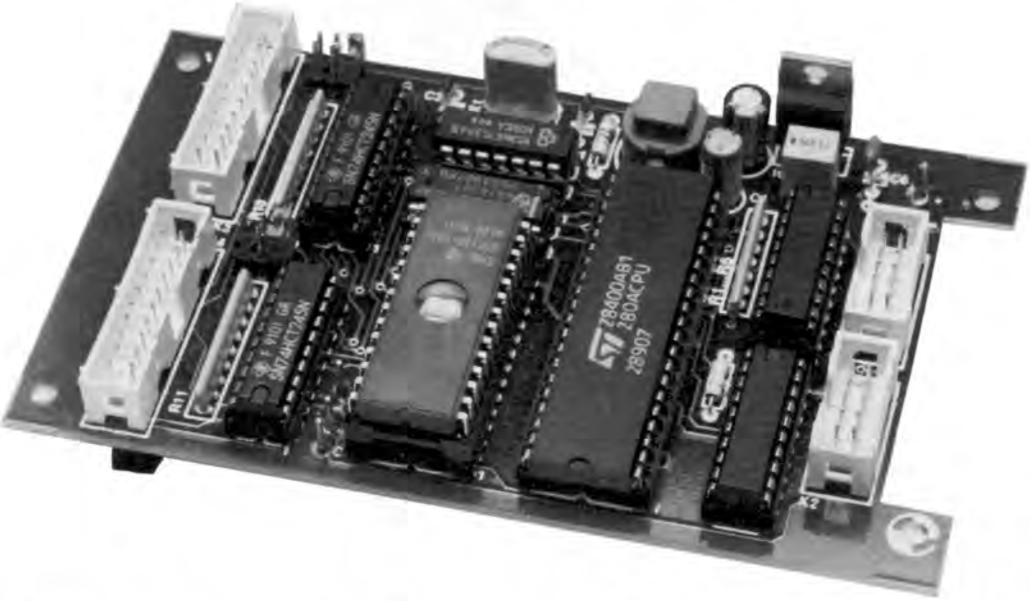
Alpha Software Corp., Suite 113, The Computer Complex, City Business Park, Stoke, Plymouth PL3 4BB. Phone 0752 606 881.

### PRINTED-CIRCUIT SERVICE

Graham Slee, who works at Audiotronics, provides what may well be a unique service in the electrical/electronics industry – he designs and builds bespoke boards and manufactures short runs only. He is geared up to to manufacture 10–1000 PCBs per production run. His average run is 200 and he can, if required, produce one-offs. He works from a client's drawings or will produce a circuit diagram on their behalf.

Phone Graham Slee on 0742 422 333. ■

# MINI Z80 SYSTEM



**Call it what you like: an all-time favourite, an evergreen in computer land, or just a die-hard electronic component: the Z80 8-bit microprocessor enjoys tremendous popularity because it is inexpensive, widely available and easy to program. Furthermore, a massive amount of software and paperware is available for this powerful CPU. Here, we present a no-frills miniature computer system based on the Z80 CPU, with I/O and ROM. No RAM, no, because that is not strictly necessary for small applications if your programming is up to scratch (but we have a RAM extension up our sleeve).**

**by A. Rigby**

PROBABLY the most remarkable feature of the present computer board is the absence of RAM (random access memory). This is unusual, but in many cases the internal registers of the Z80 can function as RAM equally well. Omitting a RAM IC then allows us to cut down on components (cost), and save board space.

The block diagram of the Z80 system is shown in Fig. 1. Remarkably, the arrangement of the functions corresponds closely to that of the associated ICs on the circuit board. In fact, Fig. 1 shows the classic setup of a microprocessor system. The Z80 CPU (central processing unit) uses I/O-mapped input-output operations, which means that the CPU works with different addresses for the memory and the I/O blocks. The present system has four I/O addresses, although two further blocks of four addresses may be selected via the two I/O ports.

The I/O ports available in the system are compatible with the universal I/O interface for IBM PCs (Ref. 1), which allows the extensions originally developed for this to be connected without problems (for instance, the relay card discussed in Ref. 2).

From the block diagram it may appear that the memory address decoder is a superfluous luxury: there is only one EPROM, and that could have been connected direct to the CPU without a decoder. The decoder, however, divides the memory range into four blocks of 16 Kbyte each, and so allows RAM

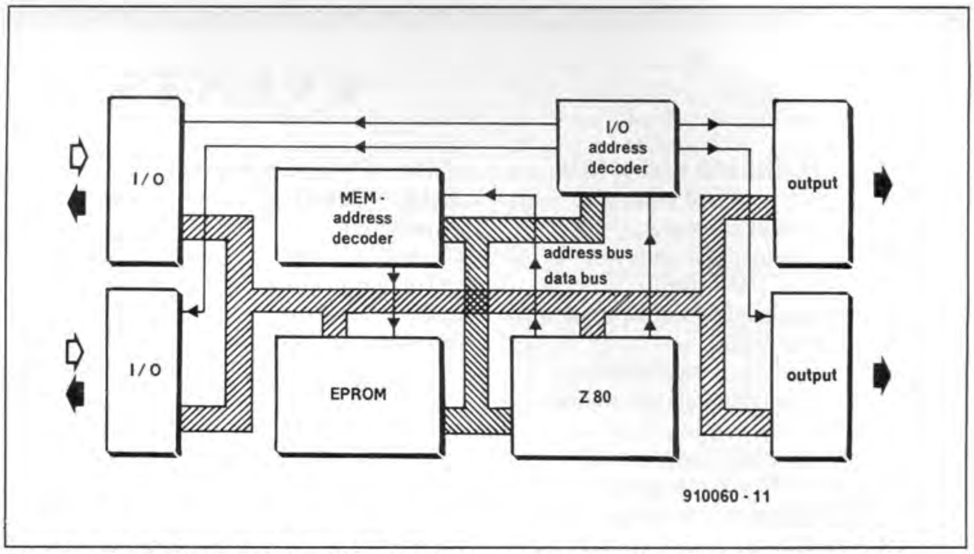


Fig. 1. Block diagram of the Z80 microprocessor system. Note the absence of RAM.

to be added (more about this next month), or more EPROMs. Moreover, the memory address decoder is formed by the remaining two 1-of-4 decoders contained in the IC used for the I/O address decoder. This means that although it may not be used in many cases, the memory decoder does not require additional hardware anyway.

## Circuit description

The circuit diagram shown in Fig. 2 closely resembles the block diagram. Only two ICs have been added: a voltage regulator and a hex inverter. Three inverters in the latter IC (IC8), are used to implement the 2-MHz clock oscillator. The unused control inputs of the Z80 (IC1) are held at +5 V via a pull-up resistor array. The reset input of the CPU is connected to an *R-C* network and a switch to ground (S1) that allows the system to be reset. The control, address and data lines of the Z80 are connected to the I/O and memory sections in the usual way.

Address decoder IC7a divides the 64-KByte memory range into four sections of

### MAIN SPECIFICATIONS

| | |
|---|---|
| **CPU:** | Z80 |
| **Clock:** | 2 MHz |
| **Memory:** | 8 K ROM (EPROM 2764)<br>or<br>16 K ROM (EPROM 27128) |
| **I/O:** | 2×8 bit input/output;<br>2×8 bit output |
| **Option:** | 8 K RAM extension |

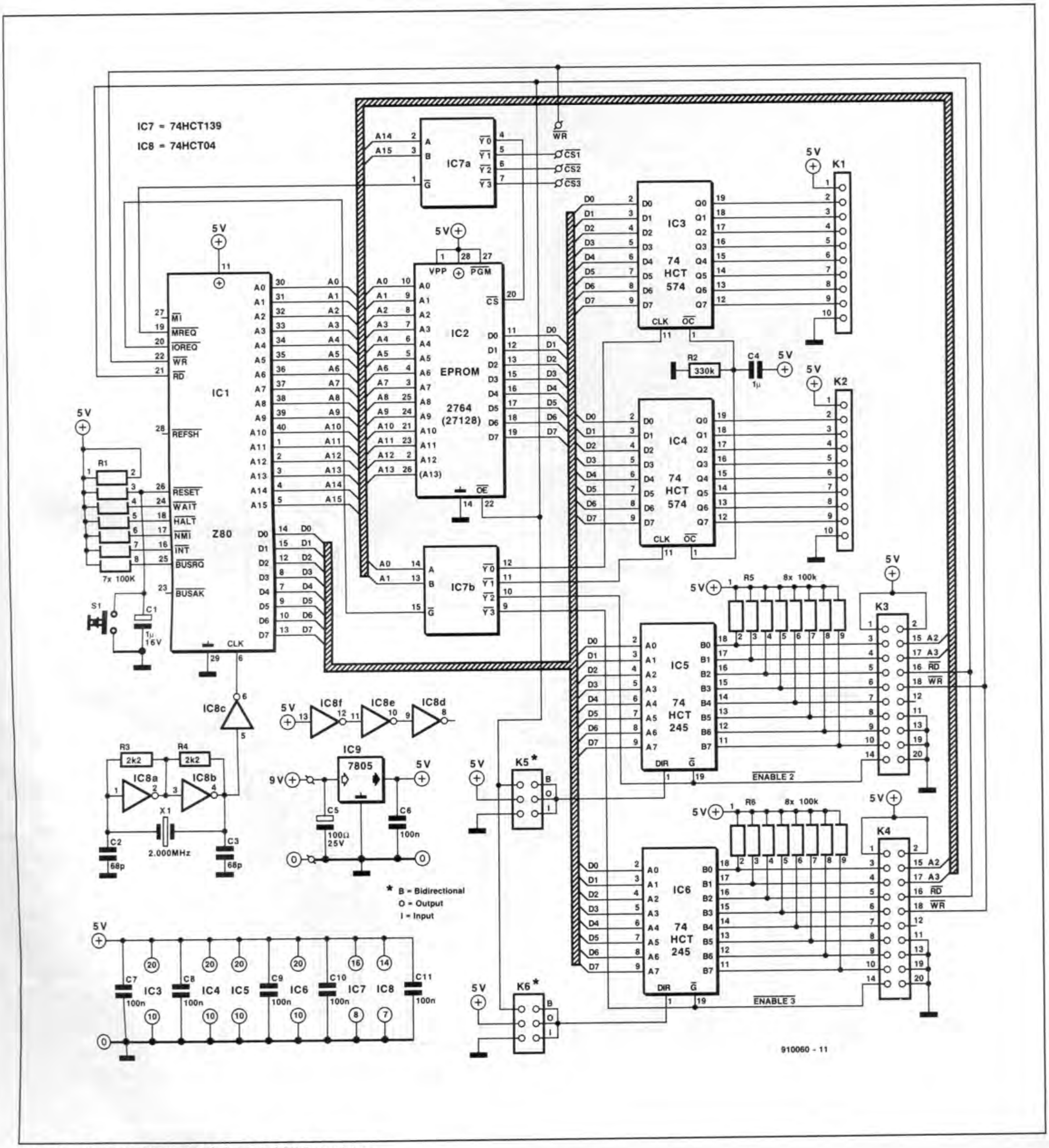


Fig. 2. Circuit diagram of the mini Z80 system.

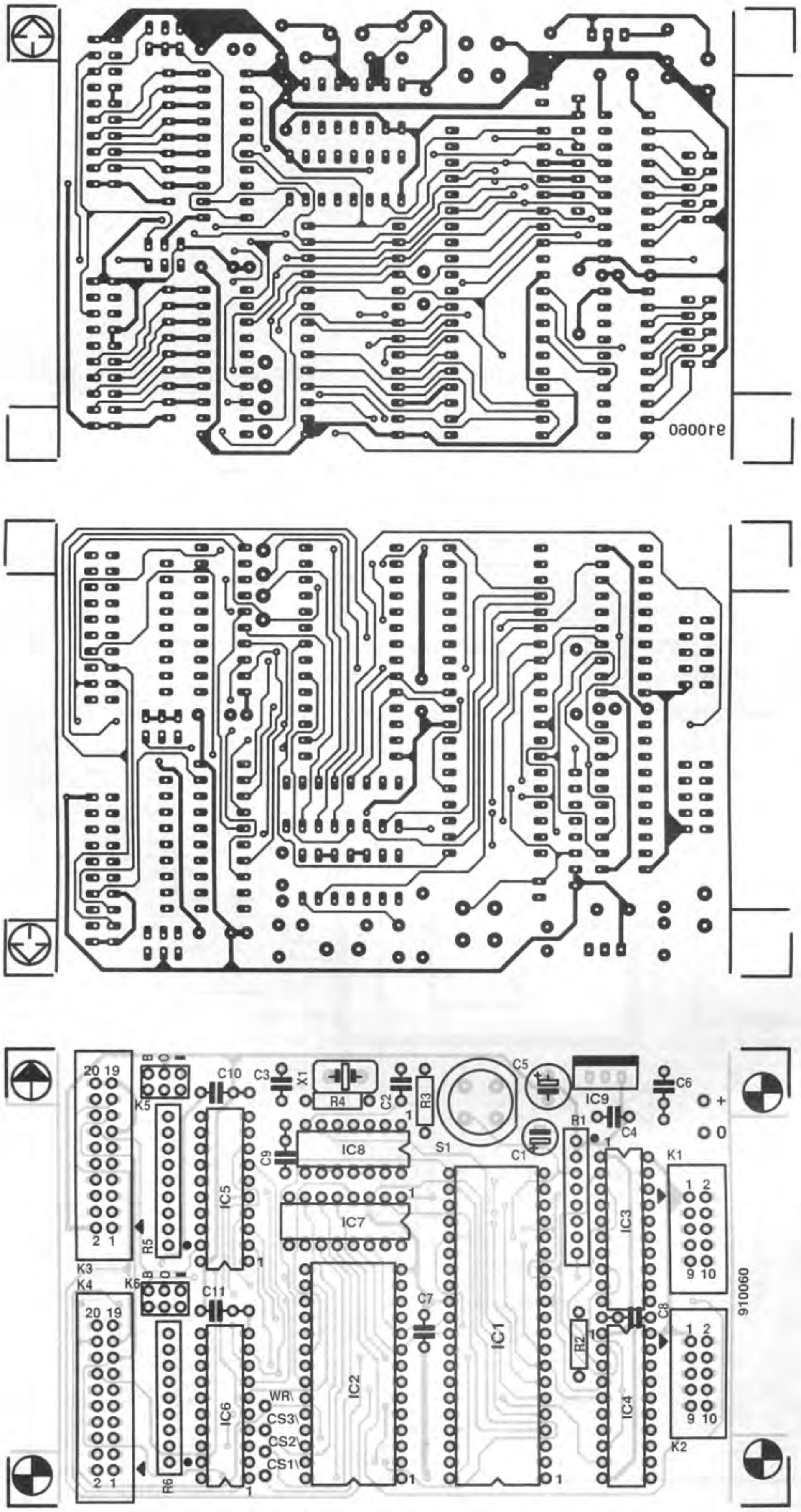


Fig. 3. Track layouts (mirror images) and component mounting plan of the PCB for the mini Z80 system.

## COMPONENTS LIST

**Resistors:**

| | | |
|---|---|---|
| 1 | 7-way SIL array 100kΩ | R1 |
| 1 | 330kΩ | R2 |
| 2 | 2kΩ2 | R3;R4 |
| 2 | 8-way SIL array 100kΩ | R5;R6 |

**Capacitors:**

| | | |
|---|---|---|
| 1 | 1µF 16V radial | C1 |
| 2 | 68pF | C2;C3 |
| 1 | 1µF solid MKT | C4 |
| 1 | 100µF 25V radial | C5 |
| 6 | 100nF | C6-C11 |

**Semiconductors:**

| | | |
|---|---|---|
| 1 | Z80 CPU | IC1 |
| 1 | 2764 or 27128 | IC2 |
| 2 | 74HCT574 | IC3;IC4 |
| 2 | 74HCT245 | IC5;IC6 |
| 1 | 74HCT139 | IC7 |
| 1 | 74HCT04 | IC8 |
| 1 | 7805 | IC9 |

**Miscellaneous:**

| | | |
|---|---|---|
| 2 | 10-way box header | K1;K2 |
| 2 | 20-way box header | K3;K4 |
| 2 | 6-way box header | K5;K6 |
| 1 | push-button | S1 |
| 1 | quartz crystal 2.00MHz | X1 |
| 1 | Enclosure 150×80×55mm, e.g. Bopla E440VL | |
| 1 | printed circuit board | 910060 |

16 kByte, so that so-called mirror areas are avoided. Only if an 8-KByte EPROM is used, its contents are duplicated in the upper half of the 16-KByte area reserved for it. The EPROM on the mini Z80 card is located in the range that starts at address 0000, where the CPU starts after a reset. The other signals supplied by the MEM address decoder, and the write signal ($\overline{\text{WR}}$), are available on the PCB for use by external circuits, such as a RAM or EPROM extension.

I/O address decoder IC7b makes use of address lines A0 and A1 only. This means that the I/O addresses do have 'mirror locations': the same IC is selected every four addresses. Since the read and write lines are not used in the I/O address decoder, you must take care not to write to input devices, or read from output devices, on penalty of destroying the CPU. Note, however, that addresses 0 and 1, at which the two 8-bit outputs, IC3 and IC4, reside, can be read without problems.

The next two addresses, 2 and 3, are occupied by two bidirectional ports, IC5 and IC6, and must be used more carefully. These ports can be set to function as an input, an output, or a bidirectional device with the aid of jumpers. When IC5 or IC6 are used as input devices, a write operation to them may damage the CPU or the addressed IC, since in that case two outputs are interconnected, which results in a virtual short-circuit. When used as output devices, a read operation to IC5 or IC6 is not harmful. In bidirectional mode, the CPU is protected reasonably well against output conflicts, and it then depends

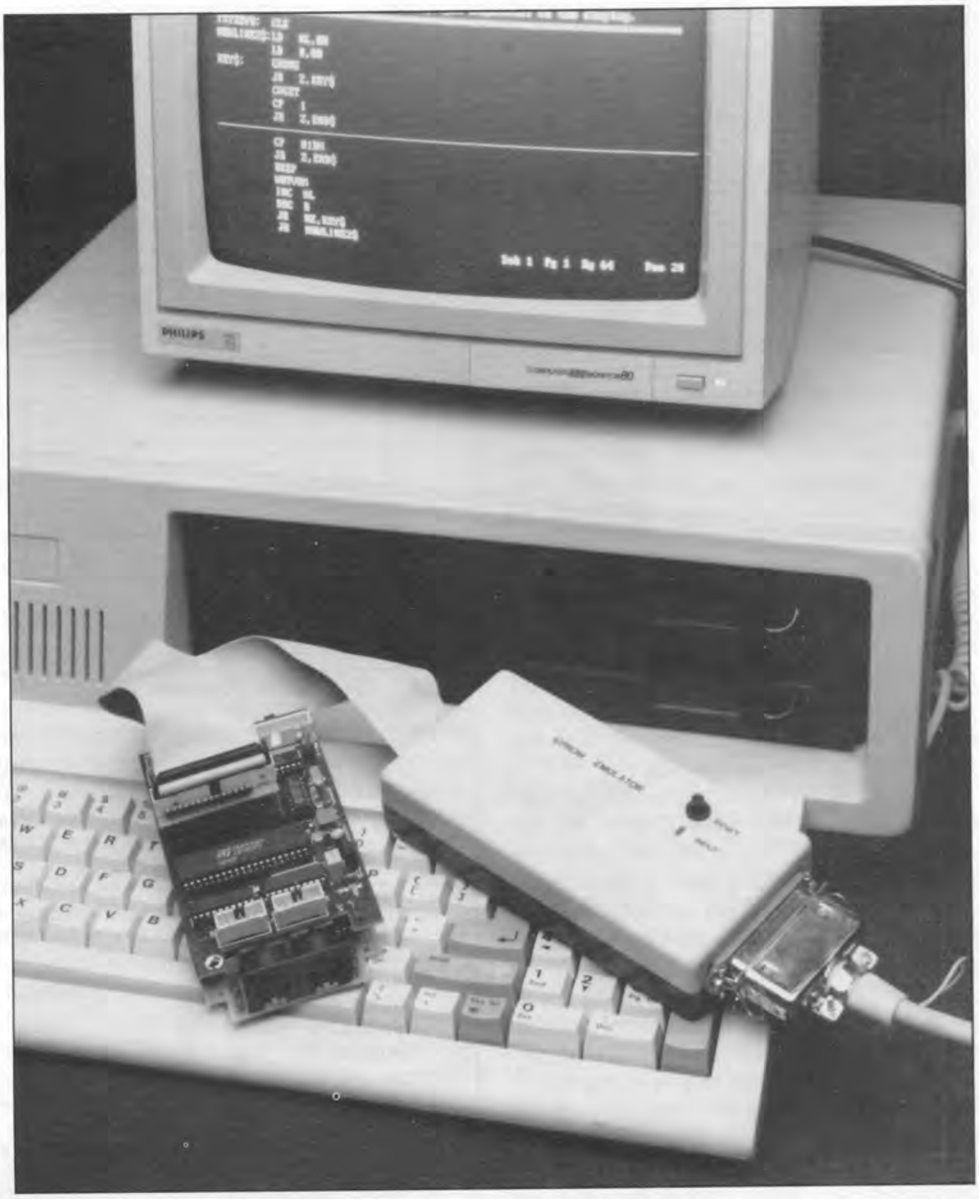


Fig. 4. Undoubtedly the most flexible way of developing software for the Z80 board is by means of an EPROM emulator and a PC running a Z80 assembler.

```
;*******************************************************
;         SIMPLE TEST PROGRAM FOR MINIZ80 BOARD
;*******************************************************
;         IC5 and IC6 jumpers set for input only
;         Be careful, a write can be destructive
;*******************************************************

output1:  equ   0                         ;address for K1
output2:  equ   1                         ;address for K2
input1:   equ   2                         ;address for K3
input2:   equ   3                         ;address for K4

          org   00h                       ;program start address

begin:    ld    a,0                       ;initialize outputs
          out   (output1),a
          out   (output2),a
loop:     in    a,(input1)                ;read input from K3
          cpl                             ;invert each bit
          out   (output1),a               ;output to K1
          in    a,(input2)                ;read input from K4
          cpl                             ;invert each bit
          out   (output2),a               ;output to K2
          jr    loop                      ;loop to check inputs
```

910060-13

Fig. 5. A simple test program that presents input data in inverted form at the output.

**Table 1. I/O address overview**

| Port | I/O address | Connector |
|---|---|---|
| IC3 | 0 | K1 |
| IC4 | 1 | K3 |
| IC5 | 2+4n | K3 |
| IC6 | 3+4n | K4 |

(n = 0 – 3)

on the level supplied by the circuit connected to connector K3 or K4 whether or not a dangerous situation can arise from reading from, or writing to, IC5 or IC6. In addition to the eight datalines, connectors K3 and K4 therefore also carry the $\overline{RD}$ and $\overline{WR}$ signals, which indicate read and write operations respectively, and so enable an external circuit to disable its inputs or outputs accordingly. There are more signals on K3 and K4: one enable signal, and two address lines, A2 and A3. These allow the Z80 card to work with extensions originally developed for the universal I/O interface for PCs.

The enable signal on the extension connectors indicates that the I/O lines are addressed, so that the circuit connected can start reading or writing data. Address lines A2 and A3 give us access to a total of eight external addresses: four each via each extension connector, as shown in Table 1.

To prevent the output ports being left in an undesired state after switching on the system, the outputs of IC3 and IC4 are briefly switched to high impedance with the aid of network R2-C4, whose *R-C* constant is about three times greater than that of the CPU reset network. Provided the relevant instructions are placed right at the start of the program (i.e., from 0000 onwards), network R2-C4 affords sufficient time for the CPU to initialize the outputs properly and prevent output-to-output conflicts.

The system is completed by a voltage regulator, IC9. This allows a mains adaptor with an output rating of 9 V to 15 V d.c. at 300 mA to be used, which is a safe as well as inexpensive way of powering the computer.

## Construction

The design of the double-sided through-plated board used for building the Z80 system is shown in Fig. 3. This board is available ready-made through our Readers Services.

Construction is straightforward work, and merits no further discussion. Application circuits can be connected to the Z80 board either via short lengths of flatcable, or direct via the connectors. In the latter case, the Z80 card is best fitted on top of the application circuit. This ensures that the EPROM socket remains accessible for a new EPROM, an EPROM emulator, or a RAM extension. As shown in one of the photographs, such an assembly is obtained by fitting sockets to the underside of the Z80 card (see Fig. 8).

The fixing holes in the PCB are located such that the completed board is easily fitted

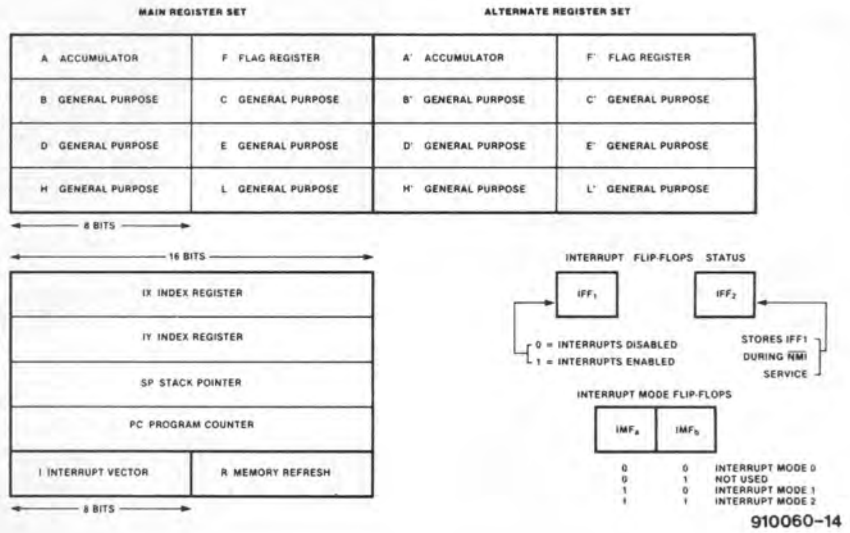


**Fig. 6. Z80 register overview.**

```
;*****************************************************
;         SIMPLE TEST PROGRAM FOR MINIZ80 BOARD
;         USING MACRO´S
;*****************************************************
;         IC5 and IC6 jumpers set for input only
;*****************************************************

output1:  equ  0                      ;address for K1
output2:  equ  1                      ;address for K2
input1:   equ  2                      ;address for K3
input2:   equ  3                      ;address for K4

;*****************************************************
;         MACRO DEFINITION
;*****************************************************

init_to_zero:
          .MACRO
          ld    a,0                   ;load initial value
          out   (output1),a           ;set output to zero
          out   (output2),a           ;set output to zero
          .MACEND

A_to_output:
          .MACRO output               ;define variable: output
          cpl                         ;invert each bit
          out   (output),a            ;output contents of A
          .MACEND

input_to_A:
          .MACRO input                ;define variable: input
          in    a,(input)             ;read input into A
          .MACEND

;*****************************************************
;         MAIN PROGRAM
;*****************************************************

          org  0h                     ;program start address

begin:    init_to_zero                ;initialize outputs

loop:     input_to_A input1
          A_to_output output1
          input_to_A input2
          A_to_output output2
          jr    loop                  ;loop to check inputs

                                                910060-15
```

**Fig. 7. Because of the absence of RAM, subroutines are best replaced by macros during the assembly phase.**

**Table 2. Non-executable instructions (without RAM)**

| | | |
|---|---|---|
| CALL | cc,nn | ;conditional subroutine<br>;call |
| CALL | nn | ;direct subroutine call |
| IM | 1 | ;interrupt mode |
| IM | 2 | ;interrupt mode |
| POP | IX | ;get data from stack |
| POP | IY | ;get data from stack |
| POP | qq | ;get data from stack |
| PUSH | IX | ;put data onto stack |
| PUSH | IY | ;put data onto stack |
| PUSH | qq | ;put data onto stack |
| RET | | ;return from subroutine |
| RETI | | ;return from interrupt |
| RETN | | ;return from non-<br>;maskable interrupt |

qq = AF, BC, DE or HL
cc = condition to execute instruction
nn = address

into the enclosure mentioned in the parts list. Where the board is used as a controller for one application only (as discussed above), the sections with the fixing holes in them may be cut off to reduce the board size even further.

## Writing programs

As already mentioned, a massive amount of literature exists on programming the Z80. In addition, assemblers and cross-assemblers for the Z80 are widely available. Lacking these, you may still program the Z80 purely by hand, i.e., by writing a machine code program, looking up the opcodes, and loading them into an EPROM. A far more flexible way of developing software is afforded by an EPROM emulator (Fig. 4), which goes round the problem of having to erase and reprogram an EPROM every time a change is required (and debugging, as you probably know, almost invariably involves a lot of changes).

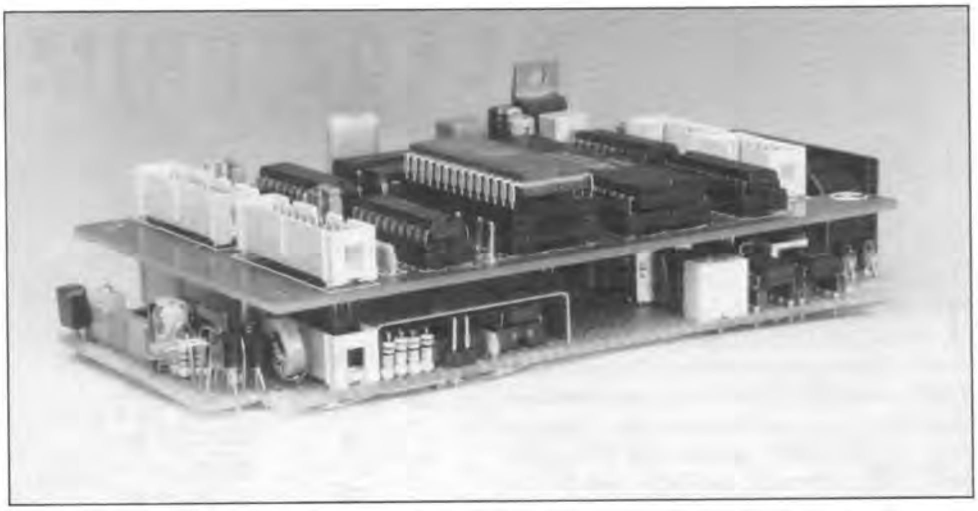


**Fig. 8. Z80 board fitted 'piggy back' on to a prototype of the RC5-code infra-red receiver described elsewhere in this issue.**

For now, you probably want to know if the card works. Well, that can be found out quite easily with the aid of the test program listed in Fig. 5. Set the two jumpers on the board to input before running the program (from EPROM). The program turns the Z80 card essentially into an input data operator. As you can see, this can be achieved without RAM, since the (many) registers of the Z80 can be used for the 'scratch' functions. Figure 6 shows a register overview of the Z80.

The absence of RAM means that a number of Z80 instructions can not be used. These instructions, listed in Table 2, are essentially those related to stack operations. As you can see, it is not possible to call interrupt and subroutines if you do not have RAM. Fortunately, this need not result in 'spaghetti software', because most assemblers support the use of macros. Macros are small pieces of machine code that are used frequently in a program, and which need to be written in source code only once. In most cases, it is possible to use variables in macros, for instance, to indicate the register or address the macro is to make use of. An example of a piece of source code containing macros is given in Fig. 7. ■

**References:**

**1.** "Universal I/O interface for IBM PCs". *Elektor Electronics* May 1991.

**2.** "Relay card for universal I/O interface". *Elektor Electronics* November 1991.

# NEW PRODUCTS

## 32-MByte Solid-state FLASH DISK module from DES

DES Innovative Electronics have developed a memory module based on flash-type memory ICs, to take over the function of a hard disk in PC XTs and ATs. The module supports various memory sizes up to 32 MByte, and can be expanded in steps of 1 MByte. Offering a read access time of 250 ns (typ.), the solid-state hard disk is about 100 times faster than a conventional drive unit. Hence, the data transfer rate that can be achieved during read operations is limited by the system bus or driver software only.

Unlike a conventional hard disk, a solid-state memory module will not wear out, and is far less sensitive to environmental factors such as dust, vibrations, etc. This makes the solid-state disk particularly suitable for use in industrial environments. Another major application area of this new product is in networks, where workstations can operate in an 'off-line' mode, having the most frequently used programs stored on a solid-state disk.

The FLASH solid-state disk is PC XT and AT bus compatible (ISA and EISA). A total of 16 SIMM sockets are available on the card to install up to 16 Mbyte using 1 MByte SIMM modules, or 32 MByte using 2 Mbyte SIMMs. An autoboot version is also available. The disk cards can be taken out of the system without losing data or programs. Battery backup is not required for this function. The FLASH disk can be erased and reprogrammed in the PC under DOS, and functions like a hard disk.

**des innovative electronics b.v., Accustraat 25, 3903 Veenendaal, Holland. Telephone: +31 8385 41301. Fax: +31 8385 26751.**

# NE602 PRIMER

by Joseph J. Carr

THE Signetics (Philips Components) NE602/SA602 is a monolithic integrated circuit containing a double balanced mixer (DBM), an oscillator, and an internal voltage regulator in a single eight-pin package (Fig. 1). The DBM operates to 500 MHz, while the internal oscillator works to 200 MHz. The primary uses of the NE602/SA602 are in HF and VHF receivers, frequency converters and frequency translators. The device can also be used as a signal generator in many popular inductor-capacitor (*L-C*) based variable frequency oscillator (VFO), piezoelectric crystal (XTAL), or swept-frequency, configurations. In this article we will explore the various configurations for the d.c. power supply, the RF input, the local oscillator and the output circuits. We will also examine certain applications of the device.

## Versions

The NE602 version of the device operates over a temperature range of 0 to +70 °C, while the SA602 operates over the extended temperature range of −40 to +85 °C. The most common form of the device is probably the NE602N, which is an eight-pin mini-DIP package. Eight-lead SO Surface mount (D-suffix) packages are also available. In this article the NE602N is featured, although the circuits also work with the other packages and configurations, including the improved follow-up types NE602AN and NE602AD which are now available.

Because the NE602 contains both a mixer and a local oscillator, it can operate as a radio receiver 'front-end' circuit. It provides very good noise and third-order intermodulation performance. The noise figure is typically 5 dB at a frequency of 45 MHz. The NE602 has a third-order intercept point of about −15 dBm referenced to a matched input, although it is recommended that a maximum signal level of −25 dBm (approx. 3.16 mW) be observed. This signal level corresponds to about 12.6 mV into a 50-Ω load, or 68 mV into the 1,500-Ω input impedance of the NE602. The NE602 is capable of providing 0.2-µV sensitivity in receiver circuits without external RF amplification. One criticism of the NE602 is that it appears to sacrifice some dynamic range for high sensitivity — a problem said to be solved in the A-series (e.g., NE602AN).

## Frequency conversion/translation

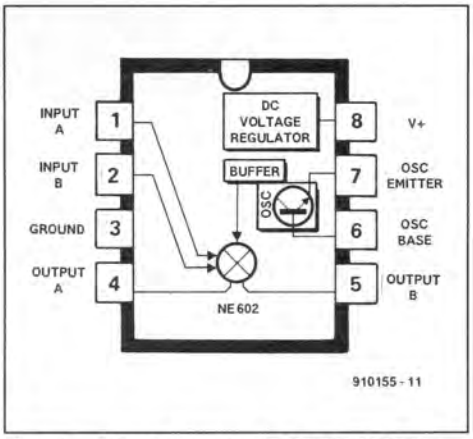


**Fig. 1. Block diagram of the NE602 showing pinouts.**

The process of frequency conversion is called heterodyning. When two signals at different frequencies ($f_1$ and $f_2$) are mixed in a non-linear circuit, a collection of different frequencies will appear at the output of the circuit. These are characterized as $f_1$, $f_2$ and $nf_1 \pm mf_2$, where $n$ and $m$ are integers. In most practical situations, $n$ and $m$ are 1, so the total output spectrum will consist at least of $f_1$, $f_2$, $f_1 + f_2$ and $f_1 - f_2$. Of course, if the two input circuits contain harmonics, additional products are found in the output. In superheterodyne radio receivers, either the sum or difference frequency is selected as the intermediate frequency (IF). In order to make the frequency conversion possible, a circuit needs a local oscillator (LO) and a mixer circuit (both of which are provided in the NE602).

The local oscillator consists of a VHF n-p-n transistor with the base connected to pin 6 of the NE602, and the emitter to pin 7; the collector of the oscillator transistor is not available on an external pin. There is also an internal buffer amplifier which connects the oscillator transistor to the DBM circuit. Any of the standard oscillator circuit configurations can be used with the internal oscillator, provided that access to the collector terminal is not required. Thus, Colpitts, Clapp, Hartley, Butler and other oscillator circuits can be used with the NE602 device, while the Pierce and Miller oscillator circuits can not.

The double balanced mixer (DBM) circuit is shown in Fig. 2; it consists of a pair of cross-connected differential amplifiers ($T_1$-$T_2$ with $T_5$ as a current source; similarly $T_3$/$T_4$ with $T_6$ working as a current source).

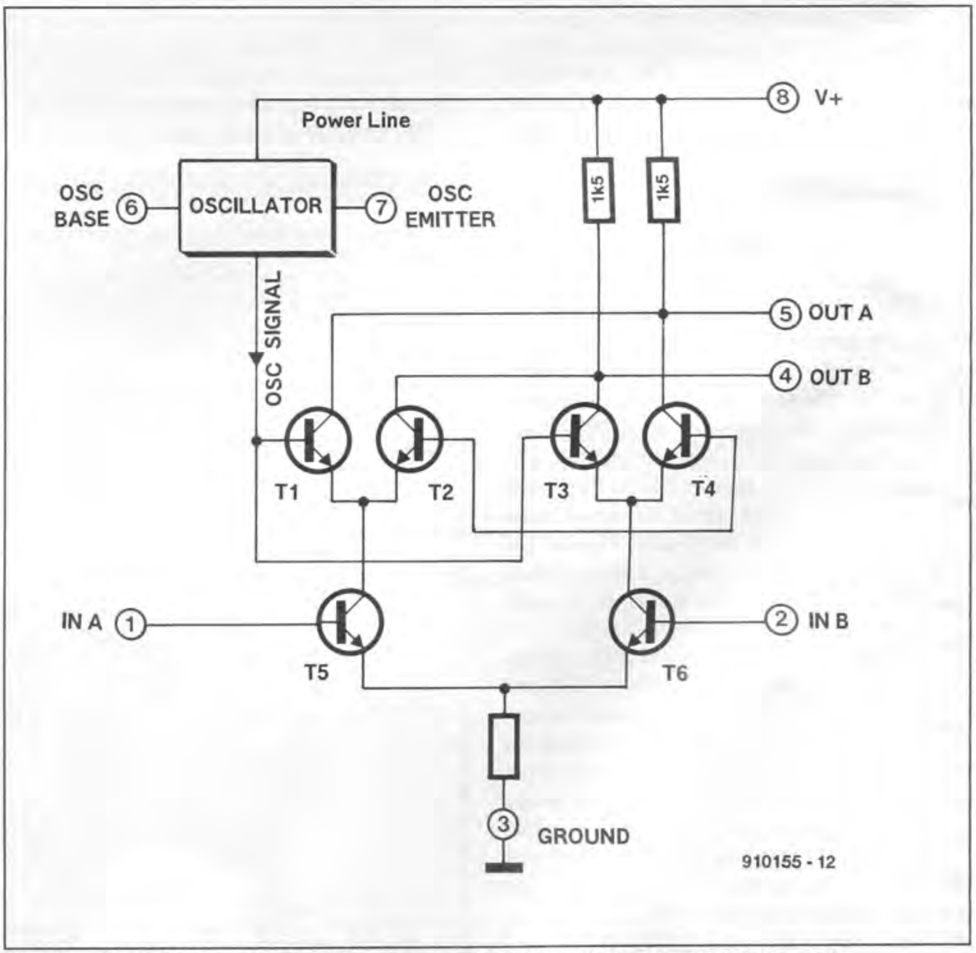


**Fig. 2. Partial internal schematic showing the Gilbert Transconductance Cell.**

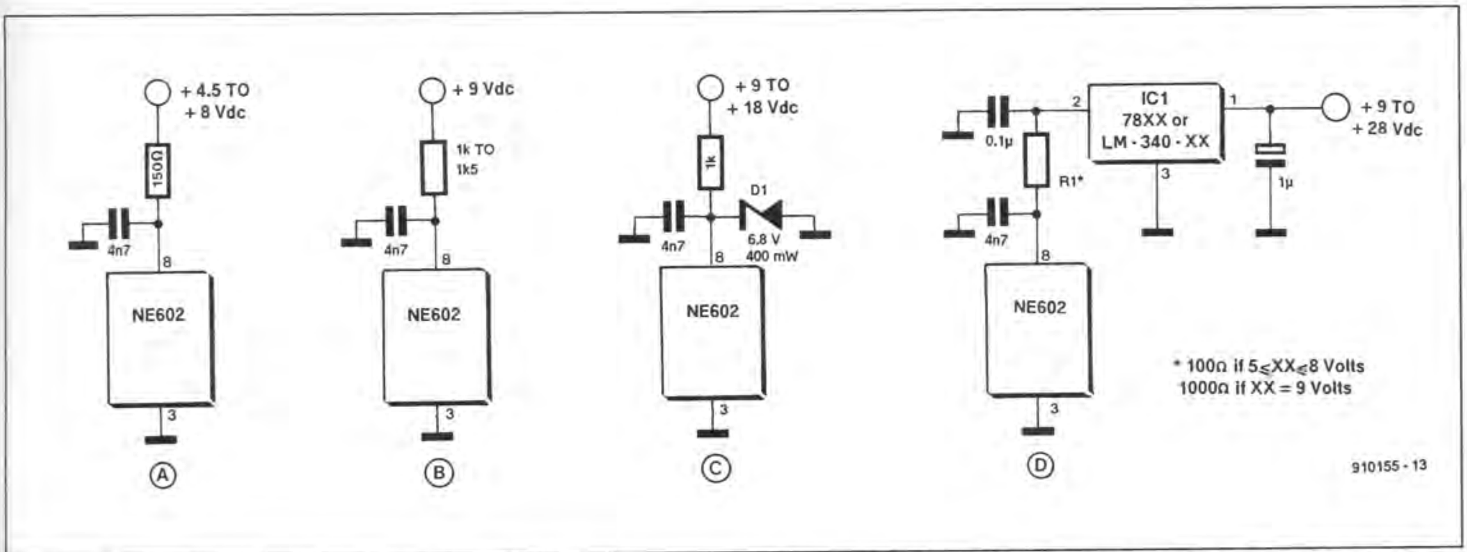


**Fig. 3. DC power supply configurations for the NE602: a) for supplies +4.5≤V≤+8 V; b) for +9-V supplies; c) zener diode regulator for +9 to +18 V supplies; d) 3-terminal IC voltage regulator for supplies from +8 to +28 V.**

This configuration is called a Gilbert Transconductance Cell. The cross-coupled collectors form a push-pull output (pins 4 and 5) in which each output pin is connected to the V+ power supply terminal through 1,500-Ω resistors. The input is also push-pull, and similarly is cross-coupled between the two halves of the cell. The local oscillator signal is injected into each cell-half at the base of one of the transistors.

Because the mixer is double-balanced, it has a key attribute that makes it ideal for use as a frequency converter or receiver front-end: suppression of the LO and RF input signals in the outputs. In the NE602 chip, the output signals are $f_1+f_2$, and $f_1-f_2$. Although some harmonic products appear, many are also suppressed because of the DBM action.

## DC power supply connections

The V+ power supply terminal of the NE602 is pin 8, and the ground connection is pin 3; both must be used for the d.c. power connections. The d.c. power supply range is to be +4.5 V to +8 V d.c., with a current drain ranging from 2.4 to 2.8 mA.

It is highly recommended that the V+ power supply terminal (pin 8) be bypassed to ground with a capacitor of 10 nF to 100 nF. The capacitor should be mounted as close to the body of the NE602 as is practical; short leads are required in radio frequency (RF) circuits.

Figure 3a shows the recommended power supply configuration for situations where the supply voltage is +4.5 to +8 V. For best results, the supply voltage should be regulated. Otherwise, the local oscillator frequency may not be stable, which leads to problems. A series resistor (100 to 180 Ω) is placed between the V+ power supply rail and the V+ terminal on the NE602. If the power supply voltage is raised to +9 V, increase the value of the series resistance an order of magnitude to 1,000 to 1,500 Ω (Fig. 3b).

If the d.c. power supply voltage is either unstable, or above +9 V, it is highly recommended that a means of voltage regulation be provided. In Fig. 3c a zener diode is used to regulate the NE602 V+ voltage to 6.8 V, even though the supply voltage ranges from +9 V to +18 V (a situation found in automotive applications). An alternative voltage regulator circuit is shown in Fig. 3d. This circuit uses a three-terminal voltage regulator to provide V+ voltage to the NE602. Because the NE602 is a very low current drain device, the lower power versions of the regulators (e.g., 78Lxx) can be used. The low-power versions also permit the NE602 to have its own regulated power supply, even though the rest of the radio receiver uses a common d.c. power supply. Input voltages of +9 V to more than +28 V, depending on the regulator device selected, can be used for this purpose. The version of Fig. 3d uses a 78L09 to provide +9 V to the NE602, although the 78L05 and 78L06 can also be used to good effect.

## NE602 input circuits

The RF input port of the NE602 uses pins 1 and 2 to form a balanced input. As is often the case in differential amplifier RF mixers, the RF input signals are applied to the base terminals of the two current sources ($T_5$ and $T_6$ in Fig. 2). The input impedance of the NE602 is 1,500 Ω shunted by 3 pF at lower frequencies, but drops to about 1,000 Ω in the VHF region.

Several different RF input configurations are shown in Fig. 4; both single-ended (unbalanced) and differential (balanced) input circuits can be used with the NE602. In Fig. 4a a capacitively coupled, untuned, unbalanced input scheme is shown. The signal is applied to pin 1 (although pin 2 could have been used instead) through a capacitor, $C_1$, that has a low impedance at the operating frequency. The signal level should be less than −25 dBm, or about 68 mV into 1,500 Ω (180 $mV_{pp}$). Whichever input is used, the alternative input is unused, and should be bypassed to ground through a low-value capacitor (1 nF to 100 nF depending on frequency).

A wideband transformer-coupled RF input circuit is shown in Fig. 4b. In this configuration, a wideband RF transformer is connected such that the secondary is applied across pins 1 and 2 of the NE602, with the primary of the transformer connected to the signal source or aerial. The turns ratio of the transformer can be used to raise the source impedance to 1,500 Ω (the NE602 input impedance). Either conventional or toroidal transformers can be used for $Tr_1$. As in the previous circuit, one input is bypassed to ground through a low reactance capacitor.

Tuned RF input circuits are shown in Figs. 4c, 4d, 4e and 5. Each of these circuits performs two functions: a) it selects the desired RF frequency while rejecting others, and b) it matches the 1.5-kΩ input impedance of the NE602 to the source or aerial system impedance (e.g., 50 Ω). The circuit shown in Fig. 4c uses an inductor ($L_1$) and capacitor ($C_1$) tuned to the input frequency, as do the other circuits, but the impedance matching function is done by tapping the inductor; a d.c. blocking capacitor is used between the aerial connection and the coil. A third capacitor, $C_3$, is used to bypass one of the inputs (pin 2) to ground.

Another version of the circuit is shown in Fig. 4d. It is similar in concept to the previous one, but uses a tapped capacitor voltage divider ($C_2$-$C_3$) for the impedance matching function. Resonance with the inductor is established by the combination of $C_1$, the main tuning capacitor, in parallel with the series combination of $C_2$ and $C_3$:

$$C_{tune} = C_1 + (C_2 C_3) / (C_2 + C_3) \qquad [1]$$

The previous two circuits are designed for use when the source or aerial system impedance is smaller than 1.5 kΩ (the input impedance of the NE602). The circuit of Fig. 4e can be used in all three situations: input impedance lower than, higher than, or equal to, the NE602 input impedance, depending on the ratio of the number of turns in the primary

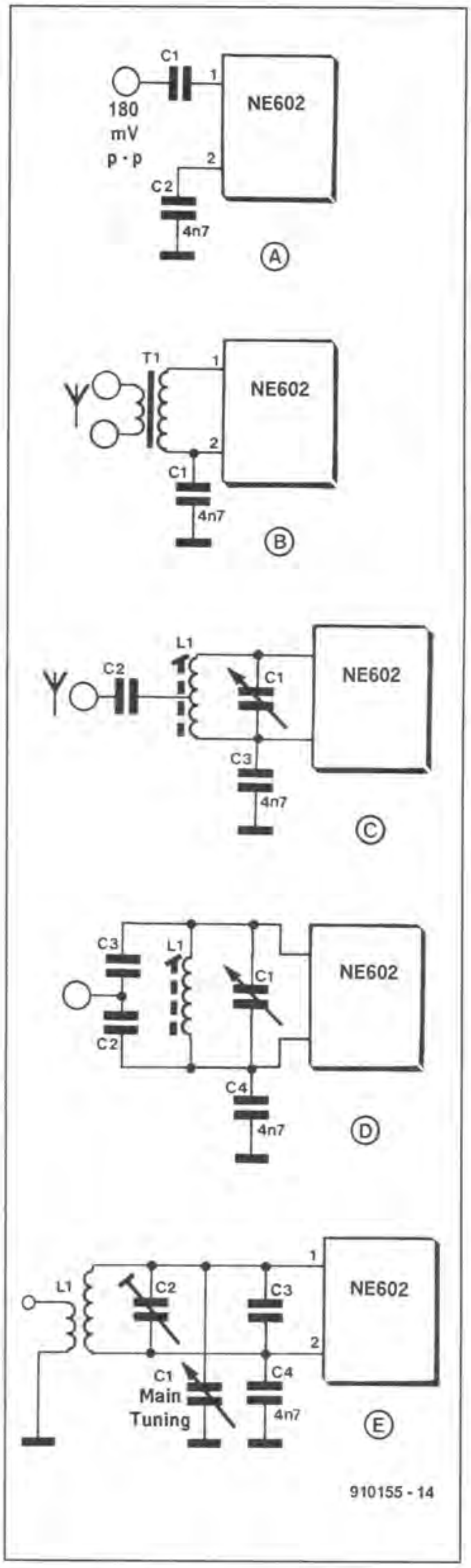


Fig. 4. **NE602 input circuit configurations: a) direct, untuned input ($V_{in} \leq 180$ mV$_{pp}$); b) broadbanded RF transformer couples signal and transform aerial impedance to 1500 Ω; c) tuned input uses a tap on the inductor for impedance matching; d) tuned input uses a tapped capacitor voltage divider for impedance matching; e) tuned transformer input that uses a grounded frame variable capacitor.**

winding (L2) to the number of turns in the secondary winding (L1). The situation shown schematically in Fig. 4e is for the case where the source impedance is smaller than the input impedance of the NE602.

The secondary of the RF transformer (L1) resonates with a capacitance made up of C1 (main tuning), C2 (trimmer tuning or bandspread), and a fixed capacitor, C3. An advantage of this circuit is that the frame of the main tuning capacitor is grounded. This feature is an advantage because most tuning capacitors are designed for grounded frame operation, so construction is easier. In addition, most of the variable frequency oscillator circuits (discussed shortly) used with the NE602 also have a grounded frame capacitor. The input circuit of Fig. 4e can therefore use a single dual-section capacitor for single knob tuning of both RF input and local oscillator.

Figure 5 shows a tuned input circuit that relies, at least in part, on a voltage variable capacitance (varactor or varicap) diode for the tuning function. The total tuning capacitance that resonates transformer secondary L2 is the parallel combination of C1 (trimmer), C2 (a fixed capacitor), and the junction capacitance of varactor diode D1. The value of capacitor C3 is normally chosen large compared with the diode capacitance so that it will have little effect on the total capacitance of the series combination C3/CD1. In other cases, however, the capacitance of C3 is chosen close to the capacitance of the diode so it becomes part of the resonant circuit capacitance.

A varactor diode is tuned by varying the reverse bias voltage applied to it. Tuning voltage $V_t$ is set by a voltage divider consisting of R1, R2 and R3. The main tuning potentiometer (R1) can be a single-turn model, but for best resolution of the tuning control use a multiturn potentiometer. The fine tuning potentiometer can be a panel mounted model for use as a bandspread control, or a trimmer model for use as a fine adjustment of the tuning circuit (a function also shared by trimmer capacitor C1).

The voltage used for the tuning circuit ($V_A$) must be well regulated, or the tuning will shift with variations of the voltage. Some designers use a separate three-terminal IC regulator for $V_A$, but that is not strictly necessary. A more common solution is to use a single low-power 9-V three-terminal IC voltage regulator for both the NE602 and the tuning network. However, it will only work when the diode needs no more than +9 V for correct tuning of the desired frequency range. Unfortunately, many varactor diodes require a voltage range of about +1 V to +37 V to cover the entire range of available capacitance.

When oscillator circuits are discussed, we will also see a version of the Fig. 5 circuit that is tuned by a sawtooth waveform (for swept-frequency operation) or a digital-to-analogue converter (for computer-controlled frequency selection).

## NE602 output circuits

The NE602 output circuit consists of the cross-coupled collectors of the two halves of the Gilbert transconductance cell (Fig. 2), and are available on pins 4 and 5. In general, it makes no difference which of these pins is used for the output — in single-ended output configurations only one terminal is used, and the other one is ignored. Each output terminal is connected internally to the NE602 to V+ through separate 1.5-kΩ resistors.

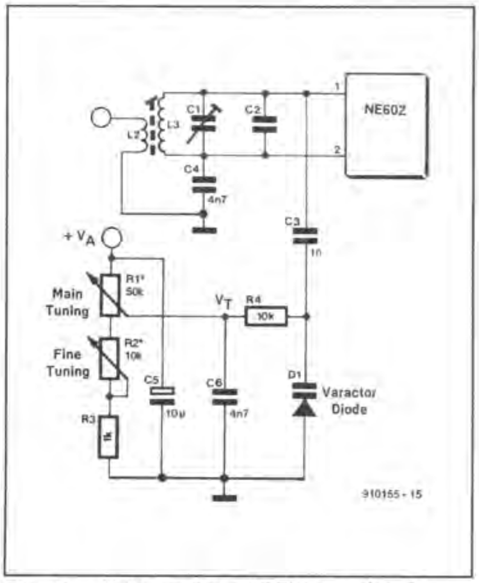


Fig. 5. **Voltage-tuned RF input circuit.**

Figure 6a shows the wideband, high impedance (1.5-kΩ) output configuration. Either pin 4 or 5 (or both) can be used. A capacitor is used to provide d.c. blocking. This capacitor should have a low reactance at the frequency of operation, so values between 1 nF and 100 nF are generally selected.

Transformer output coupling is shown in Fig. 6b. In this circuit, the primary of a transformer is connected between pins 4 and 5 of the NE602. For frequency converter or translator applications, the transformer could be a broadband RF transformer wound on either a conventional slug-tuned form or a toroid form. For direct conversion autodyne receivers the transformer would be an audio transformer. The standard 1:1 transformers used for audio coupling can be used. These transformers are sometimes marked with impedance ratio rather than turns ratio (e.g. 600 Ω:600 Ω, or 1.5kΩ:1.5kΩ).

Frequency converters and translators are the same thing, except that the 'converter' terminology generally refers to a stage in a superhet receiver, while 'translator' is more generic. For these circuits, the broadband transformer will work, but it is probably better to use a tuned RF/IF transformer for the output of the NE602. The resonant circuit will reject all but the desired frequency product; e.g., the sum or difference (IF) frequency. Figure 6c shows a common form of resonant output circuit for the NE602. The tuned primary of the transformer is connected across pins 4 and 5 of the NE602, while a secondary winding (which could be tuned or untuned) is used to couple the signal to the following stages.

A single-ended RF tuned transformer output network for the NE602 is shown in Fig. 6d. In this coupling scheme, the output terminal of the IC is coupled to the V+ supply rail through a tuned transformer. Perhaps a better solution to the single-ended problem is the circuit of Fig. 6e. In this cir-

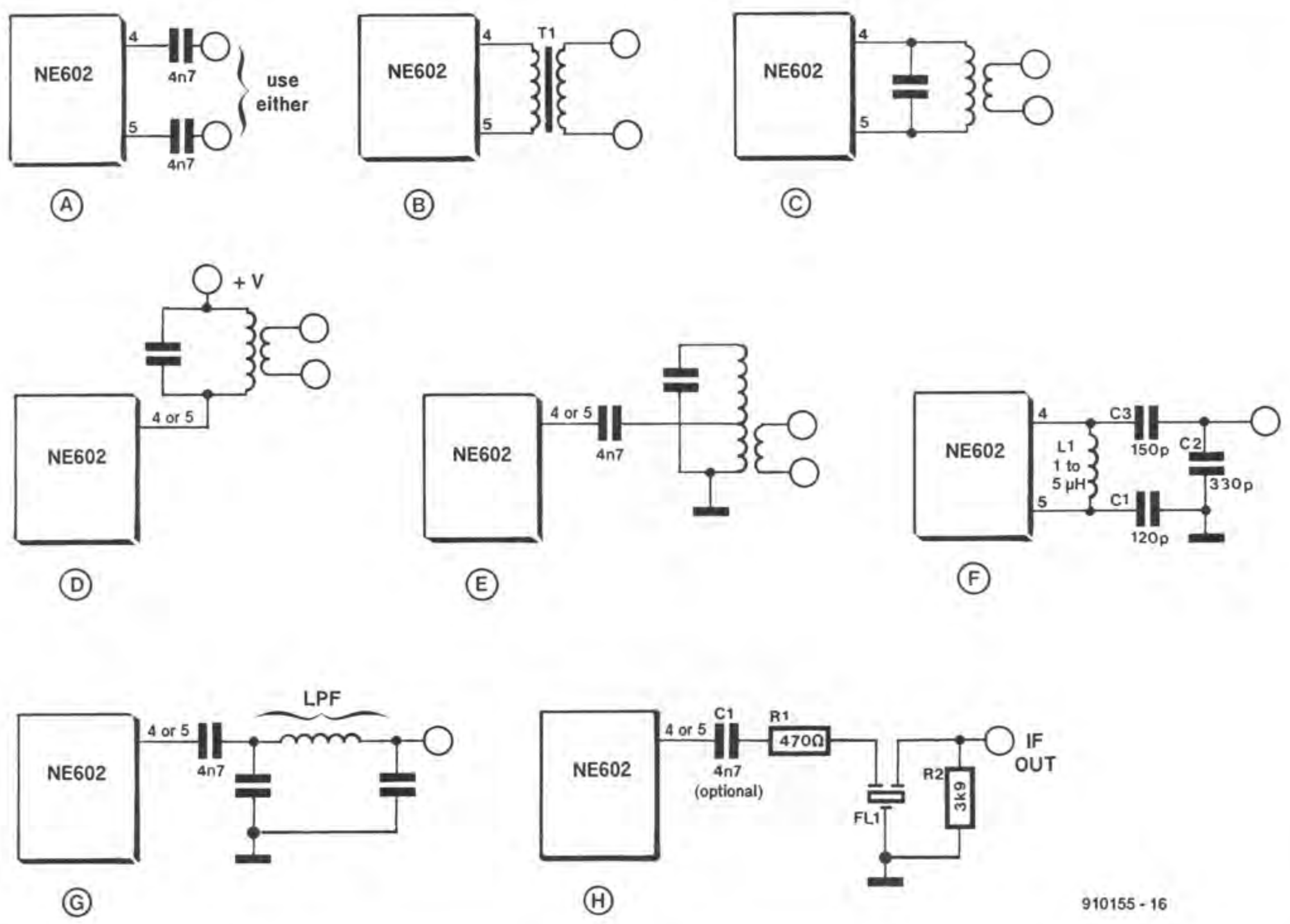


**Fig. 6. Output circuit configurations: a) direct capacitor coupled output (untuned); b) broadband transformer coupled output; c) tuned transformer output; d) tuned transformer to V+; e) grounded tuned transformer output; f) tapped capacitor tuned output (VHF circuits); g) low-pass filter output; h) filter output.**

cuit, the transformer primary is tapped for a low impedance, and the tap is connected to the NE602 output terminal through a d.c. blocking capacitor. These transformers are easily available as either 455 KHz or 10.7 MHz versions, and may also be made relatively easily.

Still another single-ended tuned output circuit is shown in Fig. 6f. In this circuit, one of the outputs is grounded for RF frequencies through a capacitor. Tuning is a function of the inductance of $L_1$ and the combined series capacitance of $C_1$, $C_2$ and $C_3$. By tapping the capacitance of the resonant circuit, at the junction of $C_2$-$C_3$, it is possible to match a lower impedance (e.g., 50 Ω) to the 1.5-kΩ output impedance of the NE602.

The single-ended output network of Fig. 6g uses a low-pass filter as the frequency selective element. This type of circuit can be used for applications such as a heterodyne signal generator in which the local oscillator frequency of the NE602 is heterodyned with the signal from another source applied to the RF input pins of the IC. The difference frequency is selected at the output when the low-pass filter is designed such that its cut-off frequency is between the sum and difference frequencies.

In Fig. 6h an IF filter is used to select the desired output frequency. These filters are available in a variety of different frequencies and configurations, including the Collins mechanical filters that were once used extensively in high-grade communications receivers (260 kHz, 455 kHz and 500 kHz centre frequencies). Current high-grade communications receivers typically use crystal IF filters centred on 8.83 MHz, 9 MHz, 10.7 MHz or 455 KHz (with bandwidths of 100 Hz to 30 kHz). Even broadcast radio receivers can be found using IF filters. Such filters are made of piezoceramic material, and are usually centred on either 260 or 262.5 kHz (AM auto radios), 455 or 460 kHz (other AM radios) or 10.7 MHz (FM radios). The lower frequency versions are typically made with 4-, 6- or 12-kHz bandwidths, while the 10.7-MHz versions have bandwidths of 150 to 300 kHz (200 kHz being most common).

In the circuit of Fig. 6h it is assumed that the low-cost (typically US$ 3) ceramic AM or FM filters are used (for other types, compatible resistances or capacitances are needed to make the filter work properly). The input side of the filter ($FL_1$) in Fig. 6h is connected to the NE602 through a 470-Ω resistor and an optional d.c. blocking capacitor ($C_1$). The output of the filter is terminated into a 3.9-kΩ resistor. The difference IF frequency resulting from the conversion process appears at this point.

One of the delights of the NE602 chip is that it contains an internal oscillator circuit that is already coupled to the internal double balanced mixer. The base and emitter connections to the oscillator transistor inside the NE602 are available through pins 6 and 7, respectively. The internal oscillator can be operated at frequencies up to 200 MHz. The internal mixer works to 500 MHz. If higher oscillator frequencies are needed, use an external local oscillator. An external signal can be coupled to the NE602 through pin 6, but must be limited to no more than about –13.8 dBm, or 250 mV across 1,500 Ω.

## NE602 local oscillator circuits

There are two general methods for controlling the frequency of a local oscillator circuit: inductor-capacitor (*LC*) resonant circuits or piezoelectric crystal resonators. We will consider both forms, but first the crystal oscillators.

Figure 7a shows the basic Colpitts crystal oscillator. It will operate with fundamental mode crystals on frequencies up to about 20 MHz. The feedback network consists of a capacitor voltage divider ($C_1$-$C_2$). The values of these capacitors are critical, and may be caluculated from:

$$C_1 = 100/\sqrt{F} \qquad [2]$$

$$C_2 = 1000/F \qquad [3]$$

Where the capacitor values are in pF and the frequency in MHz. The values resulting from these equations are approximate, but work well under circumstances where external stray capacitance does not dominate the total. However, the practical truth is that capacitors come in standard values and these may not be exactly the values required by Eqs. [2] and [3].

When the capacitor values are correct, the oscillation will be consistent. If you pull the crystal out, and then reinsert it, the oscillation will restart immediately. Also, if the power is turned off and then back on again, the oscillator will always restart. If the capacitor values are incorrect, the oscillator will either fail to run at all, or will operate intermittently. Generally, an increase in the capacitances will suffice to make operation consistent.

A problem with the circuit of Fig. 7a is that the crystal frequency is not controllable. The actual operating frequency of any crystal depends, in part, on the circuit capacitance seen by the crystal. The calibrated frequency is typically valid when the load capacitance is 20 pF or 32 pF, but this can be specified to the crystal manufacturer at the time of ordering. In Fig. 7b a variable capacitor is placed in series with the crystal in order to set the frequency. This trimmer can be adjusted to set the oscillation frequency to the desired frequency.

The two previous crystal oscillators operate in the fundamental mode. The resonant frequency in the fundamental mode is set by the dimensions of the slab (wafer) of quartz used for the crystal—the thinner the slab, the higher the frequency. Fundamental mode crystals work reliably up to about 20 MHz, but above 20 MHz the slabs become too thin for safe operation. Above about 20 MHz, the thinness of the slabs of fundamental mode crystal causes them to fracture easily. An alternative is to use overtone crystals. The overtone frequency of a crystal is not necessarily an exact harmonic of the fundamental frequency, but is close to it. The overtones tend to be close to odd integer multiples of the fundamental (3rd, 5th, 7th). Overtone crystals are marked with the appropriate overtone frequency, rather than the fundamental.

Figures 7c and 7d are overtone mode crystal oscillator circuits. The circuit in Fig. 7c is the Butler oscillator. The overtone crystal is connected between the oscillator emitter of the NE602 (pin 7) and a capacitive voltage divider that is connected between the oscillator base (pin 6) and ground. There is also an inductor in the circuit ($L_1$), and this must resonate with $C_1$ to the overtone frequency of crystal $X_1$. Figure 7c can use either 3rd or 5th overtone crystals up to about 80 MHz. The circuit in Fig. 7d is a third-overtone crystal oscillator that works from 25 MHz to about 50 MHz, and is simpler than Fig. 7c.

A pair of variable frequency oscillator (VFO) circuits are shown in Figs. 7e and 7f. The circuit in Fig. 7e is the Colpitts oscillator, while Fig. 7f is the Hartley oscillator. In both oscillators, the resonating element is an *LC* tuned resonant circuit. In Fig. 7e, however, the feedback network is a tapped capacitive voltage divider, while in Fig. 7f it is a tap on the resonating inductor. In both cases, a d.c. blocking capacitor to pin 6 is needed to pre-

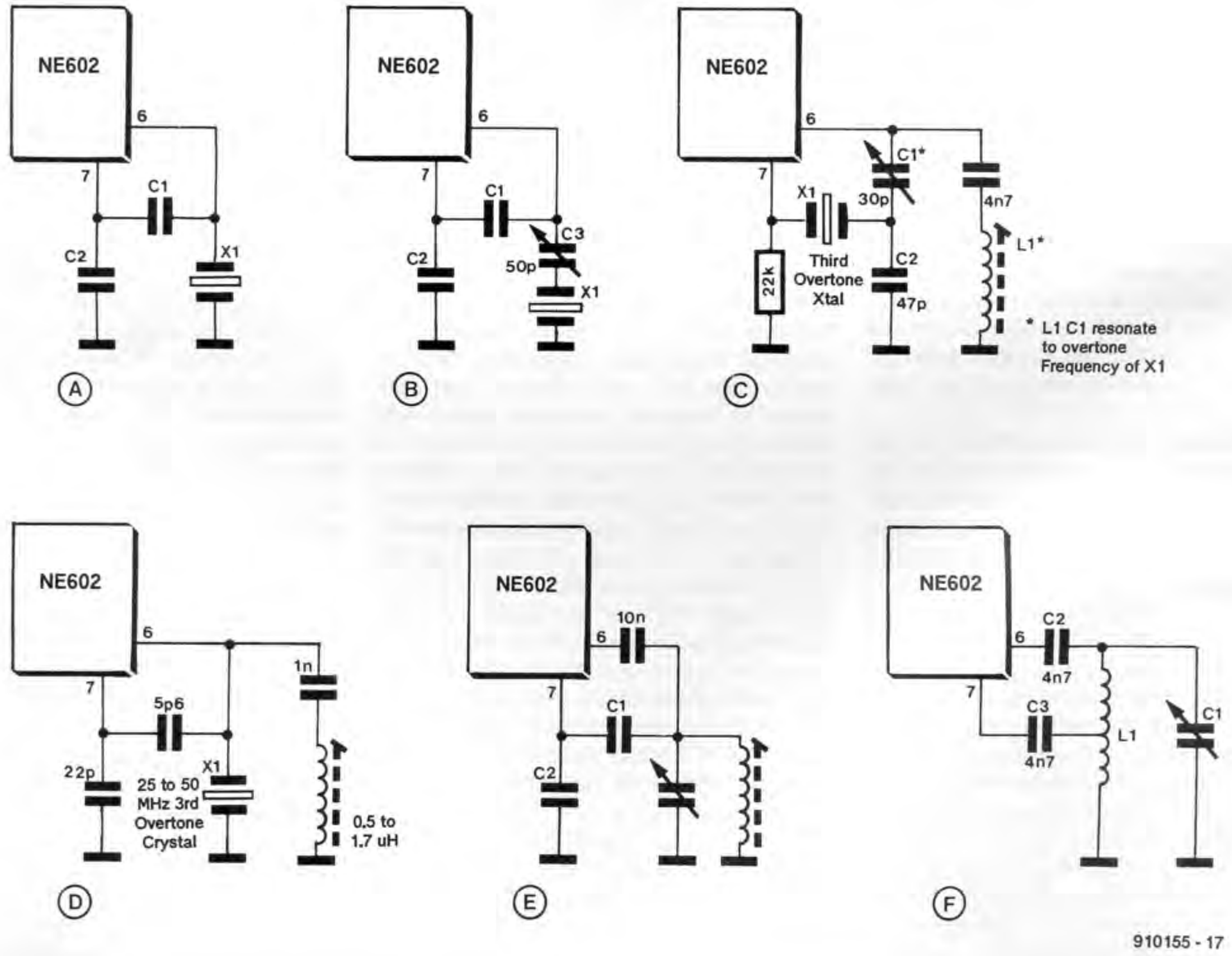


Fig. 7. Local oscillator circuits for the NE602: a) simple Colpitts crystal oscillator; b) Colpitts crystal oscillator with adjustable frequency control; c) Butler overtone oscillator for low-band VHF; d) additional overtone oscillator; e) Colpitts VFO; f) Hartley VFO.

vent the oscillator from being d.c.-grounded through the resistance of the inductor.

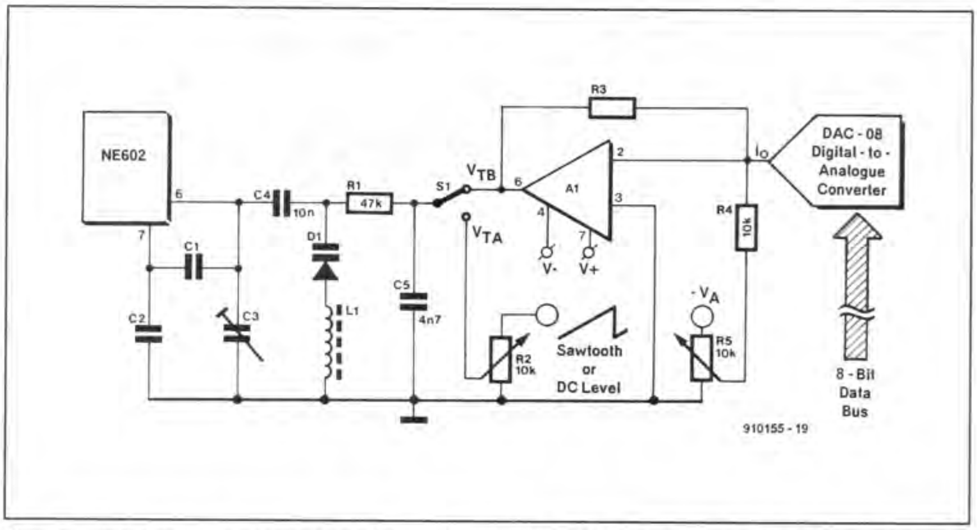


**Fig. 9. LO frequency control by either manual or digital means, according to the setting of switch S1. This circuit can be swept for FM or sweep generator use, or computer controlled by applying a binary word to the DAC input corresponding to the desired drive voltage for a specified frequency.**

## Voltage-tuned NE602 oscillator circuits

Figure 8 shows a pair of VFO circuits in which the capacitor element of the tuned circuit is a variable capacitance diode, or varactor (D1 in Figs. 8a and 8b). These diodes exhibit a junction capacitance that is a function of the reverse bias potential applied across the diode. Thus, the oscillating frequency of these circuits is a function of tuning voltage $V_t$. The version shown in Fig. 8a is the parallel-resonant Colpitts oscillator, while that in Fig. 8b is the series-tuned Clapp oscillator.

Figure 9 shows an application of the voltage-tuned oscillator (in this example, the Clapp oscillator). Two tuning modes are provided in Fig. 9. When switch S1 is in position 'A', the tuning voltage is manually set with a potentiometer, R2. If a d.c. level is applied to the top end of the potentiometer, the oscillator will operate on a discrete frequency that is a function of $V_{TA}$. If a sinusoidal waveform is applied to the potentiometer, however, the oscillator frequency will deviate back and forth in frequency modulation (FM). Or, if a sawtooth waveform is applied, the circuit becomes a sweep oscillator: the frequency will increase as the applied voltage increases, and then snap back to the lowest frequency in its range when the sawtooth drops back to zero.

When switch S1 is in position 'B', the frequency is controlled by a digital-to-analogue converter (DAC). In this case, a current output device (DAC-08 or its relatives) is shown. The output of the DAC is a current between 0 and 2 mA, which is converted into a voltage by operational amplifier A1. The tuning voltage $V_{TB}$ is the product $I_oR3$. A d.c. offset, for trimming the actual frequency, is provided by potentiometer R5 and a negative reference d.c. source, $V_A$).

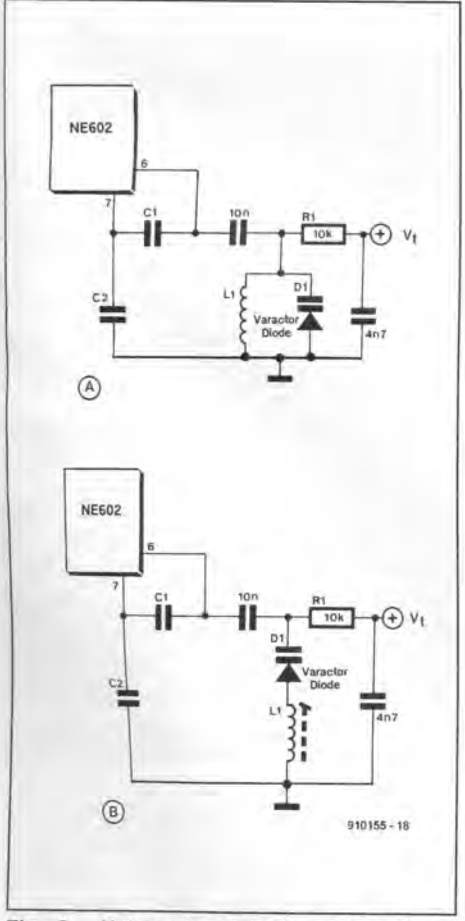


**Fig. 8. Voltage-tuned (varactor) VFO circuits: a) Colpitts; b) Clapp.**

There are several advantages to the DAC-driven version of this circuit. One is to digitally control the sweep in a manner similar to the analogue sawtooth waveform. If the digital inputs of the DAC are cycled through the binary numbers 00 to FF hex (i.e., 255 decimal) in sequence, the analogue output rises as a sawtooth.

Another application is to let the computer set the frequency of the oscillator. When the circuit is calibrated, you can set one of 256 discrete frequencies by sending the correct binary number to the DAC (which, of course, corresponds to a discrete voltage).

Finally, the digitally driven voltage-controlled oscillator can be programmed for a more linear frequency characteristic. Varactor diodes have a non-linear voltage vs. frequency characteristic, and therefore a non-linear frequency characteristic in a resonant circuit. A linearized look-up table stored in the computer can be used to generate the voltage that produces a series of equal discrete frequency steps for each 1-LSB change of the applied binary word.

## NE602 as an oscillator

The NE602 is usually thought to be a receiver or frequency converter, but it can also be used as an oscillator or signal generator. Normally, the LO signal and the RF signal are suppressed in the output. Figure 10 shows a generic circuit that will allow the LO signal to appear at the output (no RF or IF signal appears). In this circuit, one RF input (pin 2) is bypassed to ground for RF, while the other input (pin 1) is grounded for d.c. through a 10-kΩ resistance.

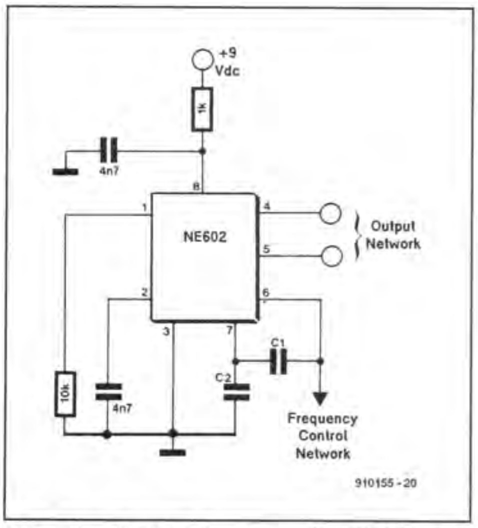


**Fig. 10. Method for using the NE602 as a signal generator.**

## Conclusion

The NE602 is a well-behaved RF chip that will function in a variety of applications from receivers, to converters, to oscillators, to signal generators. Good luck. ■

# COMPUTER-CONTROLLED WEATHER STATION

## PART 3: WINDSPEED AND DIRECTION METER

**Having dealt with sensor interfaces that measure temperature and relative humidity, we now tackle two other important meteorological parameters: the speed and direction of that eternal friend or foe of ours, the wind.**

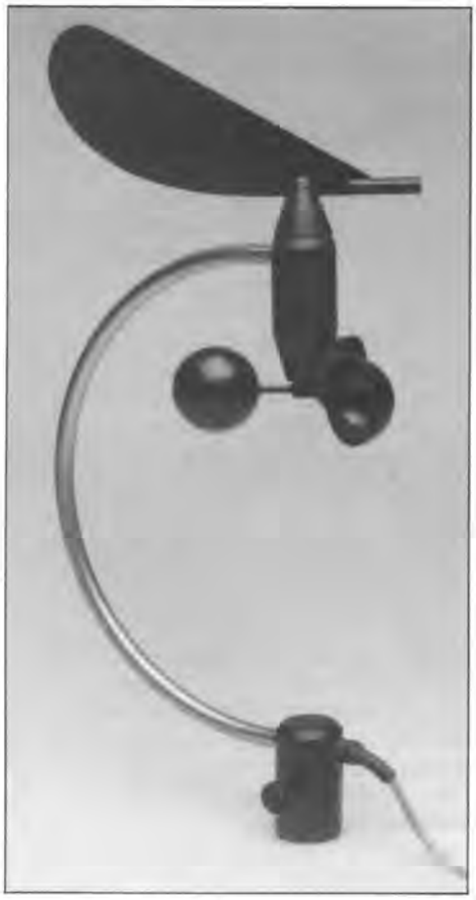


Fig. 1. This ready-made unit contains all the mechanical parts needed to measure wind speed and wind direction.

### MAIN SPECIFICATIONS

**Wind speed**

| | |
|---|---|
| Values: | peak; current; average |
| Range: | 0–30 m/s |
| Resolution: | 0.1 m/s |
| Sampling rate: | 2 per minute |
| Recording: | continuous (interval: 10 minutes) |

**Wind direction**

| | |
|---|---|
| Values: | 16 wind directions |
| Wind dial: | N; NNE, NE, E, ... |
| Angle: | 0–360 degrees |
| Resolution: | 22.5 degrees |
| Sampling rate: | 18.2 Hz |
| Recording: | continuous (interval: 10 minutes) |

**Software**

Memory-resident (TSR) data logger plus full-colour graph display program

**by J. Ruffell**

OF all factors that determine the weather, wind and precipitation are the ones that matter most to us. Since the wind brings us cold or warm air, it contributes greatly to our feeling comfortable or not, out of doors. Particularly on a cold winter's day, the wind force and wind direction have a considerable effect on the perceived temperature: when the air temperature is, say, a few degrees below zero, a stiff breeze can make it feel as cold as minus 20 degrees. This is the so-called chill factor. Of all living creatures, only mammals have this impression because their blood circulation, skin and body liquid evaporation system work in such a way that the body temperature is held constant.

Apart from having an effect on the perceived temperature, the wind can also cause problems and become a tremendous danger when its force increases from a breeze to a storm (wind force 10 or greater on the Beaufort scale).

The wind direction is measured because it is often an indication of the type of weather and related temperature we can expect. In areas close to, or surrounded by, the sea, wind from the sea has a cooling effect, while wind from the inland usually brings relatively warm air. This situation exists in the summer months, when the sea water is 'colder' than the land. In the winter months, the sea works as a thermal buffer because it forms a large source of residual heat, built up during the summer. Hence, coastal regions are often warmer in the winter. Also note that air carried over land is much drier than air carried over sea. In conclusion, wind speed and wind direction are important parameters to meteorologists, and play a significant role in weather forecasting.

## The sensors

Because repeatable, accurate measurements of the wind speed and wind direction require standardized sensors, we propose the use of a ready-made unit for this. The combined sensor is shown in Fig. 1. Its output signals are fed to the PC measurement card (Ref. 1) at the heart of our weather station. The PC runs a program that converts the sensor signals into information that is meaningful to us.

The wind direction meter consist of a vane secured to a spindle. The spindle is attached to a transparent disk with a Gray code on it. The advantage of the Gray code is that one bit changes between two successive positions of the vane, which allows us to implement a basic error checking procedure. The sensor proper consists of four slotted opto-couplers that 'read' the code on the disk. This means that the wind direction is fed to the PC in the form of a 4-bit code. Hence, the sensor is capable of indicating 16 wind directions. This is sufficient for most purposes, and meteorologists never seem to use a more accurate scale anyway.

The connection of the wind direction sensor output to the PC measurement card involves more precautions than one would expect, and this matter is taken up in detail further on.

The wind speed, which is later converted into a corresponding value that indicates the wind force, is measured with the aid of an anemometer. As you can see from Fig. 1, this consists of three small arms secured at angles of 120° to a vertical spindle. Each full spindle revolution results in 12 output pulses. Hence, the computer need only measure the frequency of the output signal of the wind speed sensor, and convert this into a normalized value (see Table 1).

## Lightning protection

Since the wind speed and direction sensor assembly is usually fitted on the roof or in another elevated location, fairly long cables may be required to bring the output signals to the computer. As far as the digital signals are concerned that travel along this cable, there are no difficulties. A problem, though, is formed by the voltages induced in the cable by lightning. Without suitable precautions, lighting that strikes close to your home can turn your costly PC into scrap metal and electronics. It is for this reason that we have to make sure that induced voltages are shunted off in the safest possible manner.

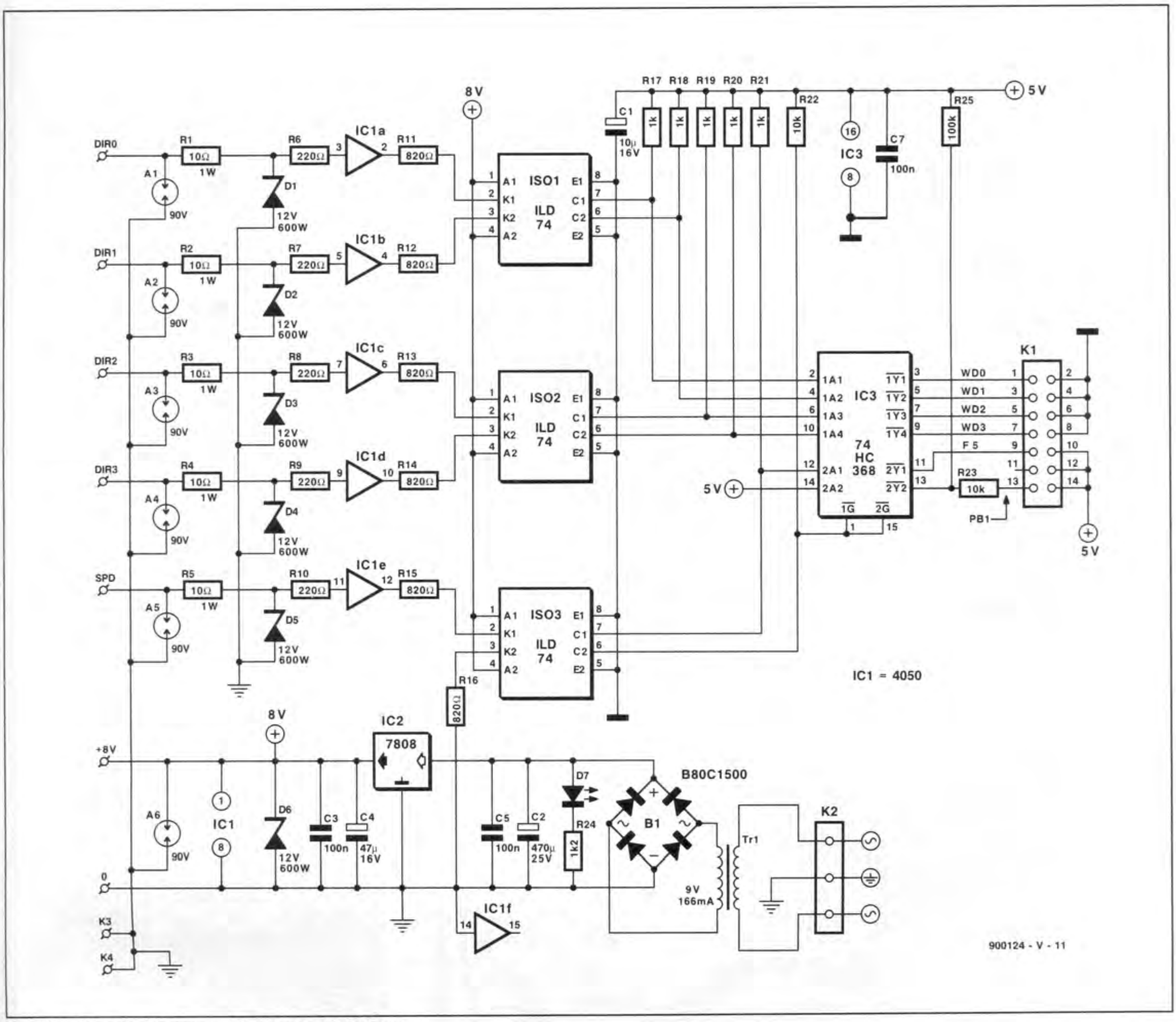


Fig. 2. Circuit diagram of the sensor interface.

**Table 1. Wind force measures**

| Beaufort | m/s | km/h | mph | knots | Description |
|---|---|---|---|---|---|
| 0 | 0–0.4 | 1.6 | 1 | 1 | calm |
| 1 | 0.4–1.4 | 1.6–6 | 1–3 | 1–3 | light air |
| 2 | 1.4–3 | 6–11 | 4–7 | 4–6 | slight breeze |
| 3 | 3–5 | 12–19 | 8–12 | 7–10 | gentle breeze |
| 4 | 5–8 | 20–29 | 13–18 | 11–16 | moderate breeze |
| 5 | 8–11 | 30–39 | 19–24 | 17–21 | fresh breeze |
| 6 | 11–14 | 40–50 | 25–31 | 22–27 | strong breeze |
| 7 | 14–17 | 51–61 | 32–38 | 38–33 | high wind |
| 8 | 17–20 | 62–74 | 39–46 | 34–40 | gale |
| 9 | 20–24 | 75–87 | 47–54 | 41–47 | strong gale |
| 10 | 24–28 | 88–101 | 55–63 | 48–55 | whole gale |
| 11 | 28–32 | 102–115 | 64–72 | 56–63 | storm |
| 12 | 32–36 | 116–131 | 73–82 | 64–71 | hurricane |
| 13 | 37–41 | 133–147 | 83–92 | 72–80 | — |
| 14 | 42–46 | 148–165 | 93–103 | 91–89 | — |
| 15 | 47–50 | 165–182 | 104–114 | 90–99 | — |
| 16 | 51–56 | 183–200 | 115–125 | 100–108 | — |
| 17 | 57–60 | 201–217 | 126–136 | 109–118 | — |

Note, however, that the measures taken here to achieve this do **not** afford protection against direct 'hits' on the sensor, the cable or the PC itself, or even the mains wiring via which the system is powered. Remember, the proposed protection is effective and adequate for **induced voltages only**. Electrical systems are very difficult to protect against direct lightning hits, and you may want to consider having a lightning conductor fitted to your home to deal with this problem.

## The interface

The main function of the circuit shown in Fig. 2 is to feed the sensor output signals to the computer whilst affording protection against voltages induced on the (long) downlead cable. Every sensor input is connected to ground via a surge arrester (A1–A6) with a spark-over voltage of 90 V. The surge arrester is a glass tube filled with a noble gas, and is capable of suppressing voltage peaks within 1 µs at peak currents up to 10 kA, or continuous currents of 20 A. Although these arresters are pretty fast-acting

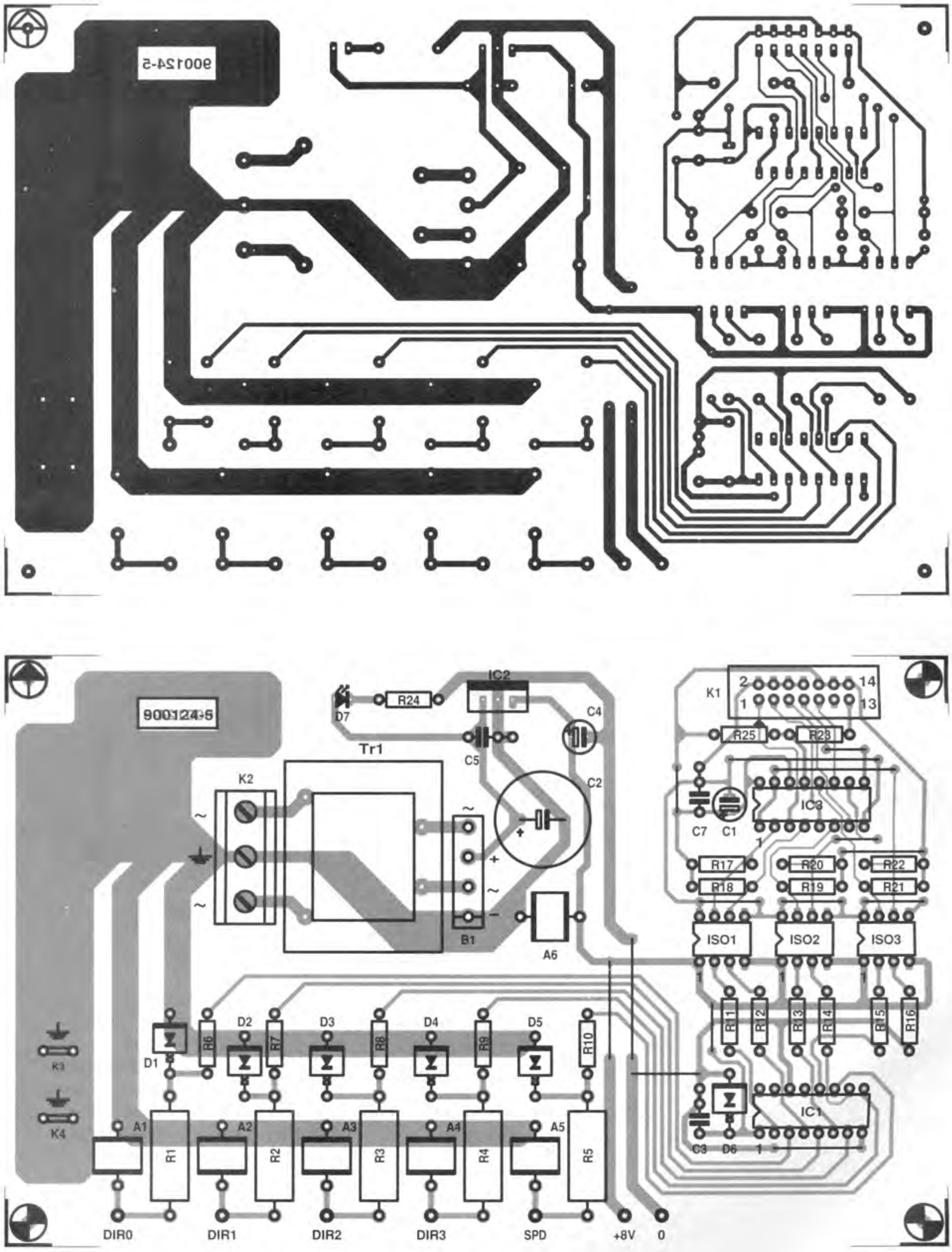


**Fig. 3. Track layout (mirror image) and component mounting plan of the PCB designed for the interface.**

devices, they are not sufficient to protect the sensitive electronics in the circuit. Therefore, each input has additional protection in the form of a very fast 12-V zener diode (D1–D6). The response time of these devices is 1 ps (typically), which is fast enough for adequate protection against overvoltages. As soon as the zener diode starts to conduct, the overvoltage is turned into heat by the associated series resistor (R1–R5).

The buffers used here are Types 4050 which are capable of handling signals levels up to 20 V at a supply voltage of 8 V. This means that the zener voltage is low enough for the buffers to operate safely at all times. Resistors R6–R10 protect the buffers against negative input voltages. The buffer outputs are capable of sinking relatively high cur-

## COMPONENTS LIST

**Resistors:**

| | | |
|---|---|---|
| 5 | 10Ω 1W | R1-R5 |
| 5 | 220Ω | R6-R10 |
| 5 | 820Ω | R11-R16 |
| 5 | 1kΩ | R17-R21 |
| 2 | 10kΩ | R22;R23 |
| 1 | 1kΩ2 | R24 |
| 1 | 100kΩ | R25 |

**Capacitors:**

| | | |
|---|---|---|
| 1 | 10μF 16V radial | C1 |
| 1 | 470μF 25V radial | C2 |
| 3 | 100nF | C3;C5;C7 |
| 1 | 47μF 16V radial | C4 |

**Semiconductors:**

| | | |
|---|---|---|
| 6 | BZT03C12 (12V/800W; Philips) or 1N5634 (8V9/1500W; General Semiconductor Industries) | D1–D6 |
| 1 | LED red dia. 3mm | D7 |
| 1 | CD4050 | IC1 |
| 1 | 7808 | IC2 |
| 1 | 74HC368 | IC3 |
| 3 | ILD74 dual optocoupler (Siemens) | ISO1;ISO2; ISO3 |
| 1 | B80C1500 | B1 |

**Miscellaneous:**

| | | |
|---|---|---|
| 1 | 14-way male box header | K1 |
| 1 | 3-way PCB terminal block; pitch 7.5mm | K2 |
| 2 | PCB-mount straight spade terminal | K3;K4 |
| 6 | A81-C90X surge arrester (90V; Siemens) | A1–A6 |
| 1 | 9V/166mA (e.g. Monacor/ Monarch VTR1109) | Tr1 |
| 1 | Printed circuit board | 900124-5 |
| 1 | Control software on disk | ESS1641 |
| 1 | 8-way DIN socket; 180°+2×41° (B81S) | |
| 1 | Mains appliance socket with earth connection | |
| 1 | Metal enclosure 185×119×51mm (Hammond 1590D) | |
| 1 | Miniature wind speed and wind direction sensor assembly. Type 455, with bracket and mounting hardware. Supplied via: Mierij Meteo, Tuinstraat 1-3, 3732 VJ De Bilt, Holland. Telephone: +31 30 200064. | |

rents, which is useful for the driving of opto-couplers ISO1, ISO2 and ISO3.

Although the above safety measures should be adequate for most situations, a further protection has been added: the entire sensor interface is electrically insulated from the computer with the aid of opto-couplers. The outputs of these devices (ISO1, ISO2 and ISO3) supply the digital signals the computer needs to interpret the data related to the wind speed and direction. The first parameter is supplied by ISO3, the second by ISO1 and ISO2.

Since the ILD74 used here is a dual opto-coupler, and the wind speed sensor requires one output only, the remaining output is used to indicate that the circuit is powered. Hence, output C2 of ISO3 is used to enable IC3, a 74HC368. This HCMOS line driver squares up the signal edges, and so increases the noise margin with respect to ground. Note that IC3 is powered by the PC—this part of the circuit is, therefore, completely insulated from the rest of the interface.

The interface is connected to the PC measurement card via connector K1. The wind direction code is sent via datalines WD0–WD3, while frequency meter input, F5, is used for the wind speed signal.

When the power supply of the interface is switched off, the outputs of the line drivers are automatically switched to a high-impedance state. This condition is signalled to the PC by the $\overline{\text{POWER GOOD}}$ line, PB1, going high. Resistor R23 prevents the I/O port on the PC measurement card being damaged when it is set to output.

The remainder of the circuit is formed by the power supply and the associated decoupling capacitors. LED D7 is the on/off indicator. The circuit diagram shows clearly that the **protective earth** at the mains socket is connected to the **ground** of the electronics ahead of the optocouplers. This connection is absolutely necessary for the surge arresters to get rid of the induced currents. An even better solution is to connect K3 to an earthing pin—this enables the energy to bypass the rest of the electrical system.

## Construction

The construction of the interface should not pose problems because the circuit is compact, and a PCB design is available. Figure 3 shows the component mounting plan and the track layout (mirror image) of the PCB designed for the interface. To reduce stray inductance to a minimum, the surge arrester must be mounted as close as possible to the PCB. The same goes for diodes D1–D6.

On completion of the solder work, the PCB is fitted into a water-proof metal enclosure, which is earthed via connector K4. The copper track between the earth terminal on the PCB and connectors K3 and K4, and the earth tracks of the surge arresters, must be strengthened by soldering pieces of 2.5-mm (cross-sectional area) solid copper wire on them.

The sensor is connected to the sensor interface via a short flexible cable terminated into an 8-way DIN plug. The pinout of this plug is given in Fig. 4.

## The software

Once again this part of the computer-controlled weather station requires a powerful piece of software, which you can obtain through our Readers Services. As with the previous two publications on the weather station, an IBM PC or compatible is used to collect the measured data, and convert these into easily interpreted graphics images.

Procedures have been added to the latest version of Xlogger (1.2) that enable the wind speed and wind direction to be measured and recorded. A new graphics program, WIND.EXE, has been developed, and is included on the disk. In the left-hand bottom corner of the screen three coloured bars are displayed that indicate the current, the average and the peak wind speed. The scale is in m/s with a range of 0 to 30, and has a numerical readout at the extreme right.

As usual in meteorology, the average wind speed is computed progressively over the last ten minutes. The peak indicator al-

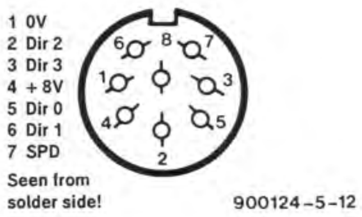


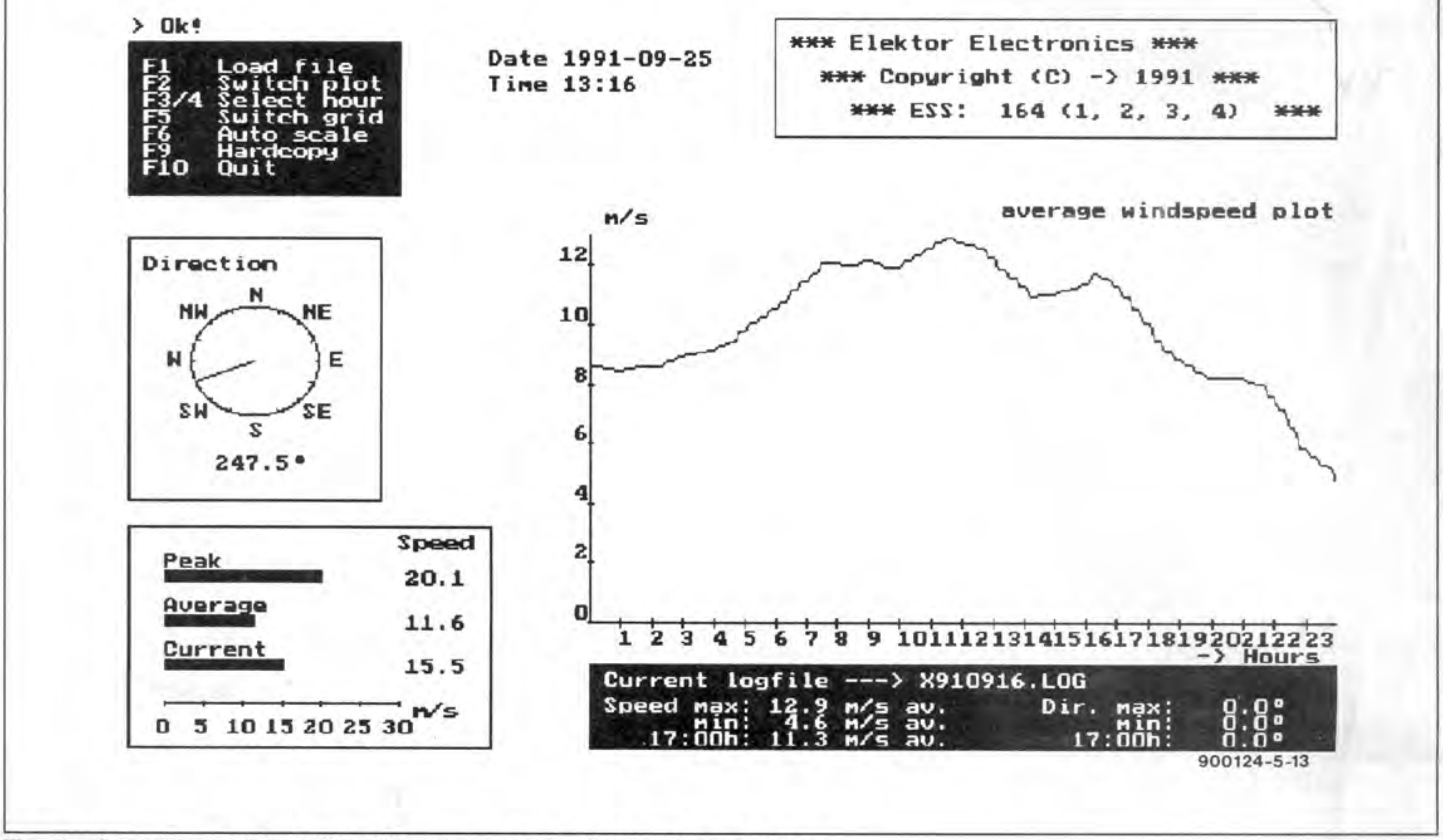
**Fig. 4. Pinout of the 8-way DIN socket, seen from the solder side.**

**Table 2a. Wind speed as a function of sensor output frequency**

| Speed (m/s) | Frequency (Hz) |
|---|---|
| 30 | 465 |
| 27 | 415 |
| 24 | 365 |
| 21 | 315 |
| 18 | 265 |
| 15 | 215 |
| 12 | 170 |
| 9 | 120 |
| 6 | 75 |
| 3 | 30 |

**Table 2b. Sensor codes as a function of wind direction**

| Direction | Code |
|---|---|
| N | 0000 |
| NNE | 0001 |
| NE | 0011 |
| ENE | 0010 |
| E | 0110 |
| ESE | 0111 |
| SE | 0101 |
| SSE | 0100 |
| S | 1100 |
| SSW | 1101 |
| SW | 1111 |
| WSW | 1110 |
| W | 1010 |
| WNW | 1011 |
| NW | 1001 |
| NNW | 1000 |



```
> Ok!
F1    Load file
F2    Switch plot
F3/4  Select hour
F5    Switch grid
F6    Auto scale
F9    Hardcopy
F10   Quit
```

```
Date 1991-09-25
Time 13:16
```

```
*** Elektor Electronics ***
  *** Copyright (C) -> 1991 ***
    *** ESS:  164 (1, 2, 3, 4)   ***
```

```
Direction
247.5°
```

```
            Speed
Peak        20.1
Average     11.6
Current     15.5
```

```
Current logfile ---> X910916.LOG
Speed max: 12.9 m/s av.          Dir. max:    0.0°
       min:  4.6 m/s av.              min:    0.0°
    17:00h: 11.3 m/s av.           17:00h:    0.0°
```

**Fig. 5. Screendump of the WIND.EXE program. The calibration is very simple.**

ways shows the highest current value (useful to measure the top wind speed during blasts), and is automatically reset at midnight.

The wind dial shown on the computer screen has the usual N, NNE, NE, etc., marks. In addition, the wind direction is indicated numerically as an angle between 0 and 360 degrees: nought degrees being North, and counting positive to the South via the East.

The wind direction is read as a single 4-bit code, and therefore takes very little processor time. Xlogger has no problems reading a wind direction code each INT-$1C interval, that is, 18.2 times per second. The wind speed and relative humidity measurement are much more complex, so that two measurements per minute are realistic. Every progressive average wind speed value is, therefore, based on the last 20 measurements.

WIND.EXE offers a graph procedure to visualize the recorded data. The by now familiar function-key menu allows you to select between a 24-hour graph for the wind direction, or one for the wind speed. The graph displayed on the screen is automatically updated after Xlogger adds a new value to the log file. A window below the graph shows the highest and lowest values recorded during the measurement. Other options of the program include: producing hard copy of the graph on a printer (Epson FX-80 compatible), retrieving measurement data at a preset time, and loading previously made log files. The diskette supplied for the present project also contains an update for the relative humidity meter and the thermometer.

## Adjustment

The function of the combined wind speed and direction sensor assembly is well documented in the form of two tables (2a and 2b) supplied by the manufacturer. These two tables are stored in the text files WSTrans.CFG (for the wind speed) and WDTrans (for the wind direction). The first file consists of the origin, 0 Hz; 0 m/s, plus ten known co-ordinates from Table 2a. WIND.EXE uses this information to interpolate the wind speed that belongs with a certain measured frequency.

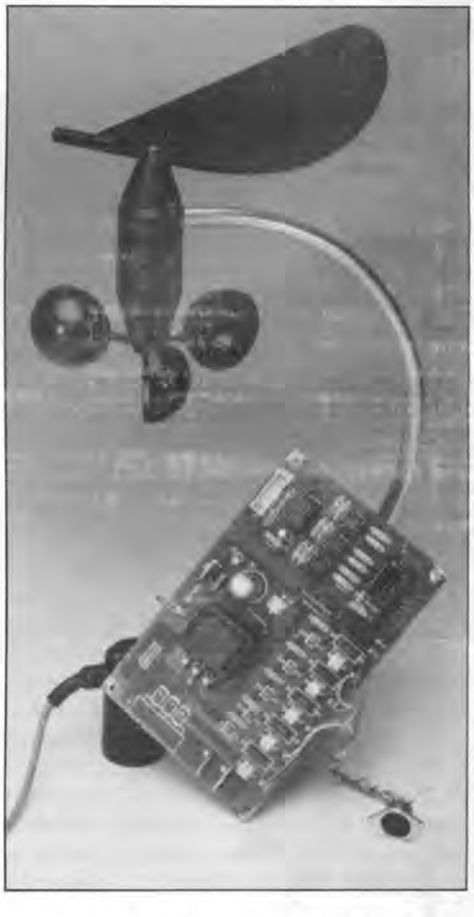
When WIND.EXE is started, a look-up table is created (in RAM) on the basis of the information contained in WDTrans.CFG. The Gray code functions as an index, and the entries are the associated wind direction in degrees. Since the hardware inverts all logic levels, the codes stored in WDTrans.CFG are inverted with respect to the table entries. The references N, NNE, NE, etc., are comment only—remember, the location (i.e., the line number) in the text file determines the associated wind direction. Taking this structure into account, only the configuration (.CFG) files need to be modified to enable other sensors to be used. ■

**Reference:**

1. "Multifunction measurement card for PCs", *Elektor Electronics* January and February 1991.

**Previous instalments in this series:**

1. Indoor/outdoor thermometer. *Elektor Electronics* March 1991.
2. Electronic hygrometer. *Elektor Electronics* October 1991.



# FAST, PRECISE THERMOMETER

by J. Ruffell

**Thermometers that depend on the Seebeck (thermoelectric) effect have been in use for many years. The thermocouples (sensors) used in these instruments are formed by two wires of dissimilar metal joined either at each end (two-terminal) or at one end (three-terminal) to form an electrical circuit. If the junctions are at different temperatures, a current will flow in the circuit. The magnitude of the current is proportional to the characteristics of the materials and the difference between the two end temperatures.These sensors are robust, inexpensive, available in a variety of shapes and sizes, and suitable for use over a wide range of temperatures.**

ALTHOUGH the PT100 thermometer published in our November 1990 issue was, by all accounts, very popular, it suffered from a serious drawback as far as many constructors were concerned: the sensor was quite expensive. The thermometer presented in this article uses a thermocouple that is much more reasonably priced. Moreover, the electronics has been kept as straightforward as possible: apart from the sensor, the thermometer requires a simple amplifier, an analogue-to-digital converter, a linearization circuit and a display. If good precision is not a serious requirement, the linearization circuit may be omitted.

The outstanding feature of the thermometer is, undoubtedly, the speed at which the temperature is measured and displayed. Whereas, for instance, a resistance-based (say, PT-100) thermometer requires up to 15 seconds to indicate the measurand, a thermoelectric thermometer does so in just one or two seconds.

The e.m.f., $U_{tc}$, developed across the junctions of the thermocouple is given by

$$U_{tc} = a + b\,\theta + c\,\theta^2,$$

where $a$, $b$, and $c$ are constants and $\theta$ is the temperature difference between the junctions. If the reference (or 'cold') junction(s) is maintained at 0 °C (the usual case),

$$U_{tc} = \alpha T^2 + \beta T,$$

where $\alpha$ and $\beta$ are constants dependent on the metals used and $T$ is the temperature of the sensing (or 'hot') junction. At temperatures below the neutral temperature ($T_N = -\beta/2\alpha$), and if $\alpha$ is small (the usual case), $U_{tc}$ is directly proportional to the temperature of the hot junction. Therefore, in a practical thermometer, the e.m.f. is

$$U_{tc} = E\,(T_s - T_r),$$

where $T_r$ is the reference temperature (cold junction), $T_s$ is the sensed temperature (hot junction), and $E$ is the voltage-temperature gradient of the thermocouple (mV K$^{-1}$). As already stated, the cold junction is traditionally held at the *ice point* (the equilibrium temperature between ice and air-saturated water

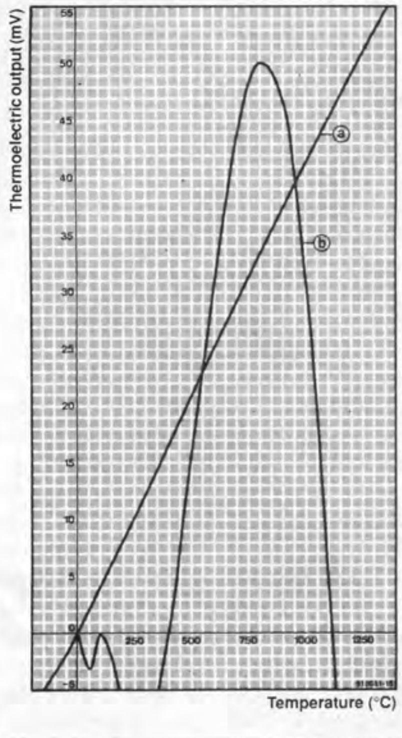


**Fig. 1. The voltage-temperature gradient of Type K thermocouples (a) is fairly linear ; the deviation from linearity at a ×100 larger scale is represented by (b).**

at standard atmospheric pressure); for practical purposes, this is 0 °C. That makes the measurement independent of the ambient temperature. In electronic thermometers, once calibration has taken place, a compensating voltage, directly proportional to the ambient temperature, is added to the e.m.f., so that, electronically speaking, the cold junction is always at 0 °C.

The temperature at the hot junction, referred to 0 °C, is multiplied by the voltage-temperature gradient $E$ to give the thermoelectric e.m.f., $U_{tc}$. The gradient can be deduced from a table of thermoelectric materials by adding the gradients of the two metals together and dividing by two. Unfortunately, not only are the tables valid for only one temperature, but the gradients are not linear, so that for precise temperature measurements a correcting network must be inserted between the thermocouple and the display circuit.

However, there are thermocouples that have a reasonably linear gradient, combined with a wide temperature range, which are not too expensive. For the present design, a Type K sensor was chosen: this consists of a chromel (NiCr) and nickel (Ni) or alumel (NiAl) combination. The gradient of this thermocouple—see Fig. 1 (a)—is fairly linear so that a linearization network is not required. The deviation from true linearity is shown in (b) on a scale ×100 that of (a). It is seen that the maximum deviation is 0.5 mV at 800 °C, which is just 1.5%.

Type T (copper-constantan) thermocouples, which are very accurate, or Type J (iron-constantan) sensors, which are more sensitive, less expensive, and slightly more accurate than Type K devices, could also have been used, but their maximum temperature—500 °C and 760 °C respectively—would not have been acceptable for the present design.

## From sensor to circuit

It is clear that the output voltage of the sensor must be magnified to an appreciable extent. The basic setup of a suitable amplifier is shown in Fig. 2. The thermo-emf, $U_{tc}$ and the compensating voltage, $U_c$ (which, remember, is a function of the ambient temperature) are added and the resulting potential, $U_s$, is amplified by a factor $A$ in an operational amplifier. The voltage-temperature gradient is 40.44 μV K$^{-1}$ at 25 °C, so that, if the signal at the output of the opamp is required to have a rate of change of 1 mV K$^{-1}$, $E$ must be amplified ×23.728.

The process may be considered in more detail with reference to Fig. 3, which shows the input stage of the thermometer. The compensating voltage is provided by a small-signal transistor whose base-emitter potential has been set at 0.6 V by R$_5$. The temperature coefficient, $\gamma$, of the base-emitter junction is –2 mV K$^{-1}$. This means that for every degree the temperature rises, the base-emitter potential drops by 2 mV. The compensating voltage thus consists of a fixed component, $U_f$, and a variable component, $\gamma T_r$. The fixed component is, of course, not wanted and is, therefore, negated by a temperature-independent offset voltage, $U_{os}$.

The currents flowing through R$_1$, R$_2$, and R$_3$ into the inverting input of the opamp are:

$$I_1 = -U_{tc}/R_1;$$

$$I_2 = (U_f+\gamma T_r)/R_2;$$

$$I_3 = U_{os}/R_3.$$

Their sum is the current, $I_4$, through R$_4$:

$$I_4 = I_1+I_2+I_3.$$

The output voltage, $U_o$, of the opamp is

$$U_o = -I_4R_4$$

$$= -R_4[-U_{tc}/R_1+(U_f+\gamma T_a)/R_2+U_{os}/R_3].$$

When the fixed component is negated, that is,

$$U_f/R_2+U_{os}/R_3 = 0,$$

it follows that

$$U_{os} = U_f(-R_3/R_2),$$

whence

$$R_3 = U_f(-R_2U_{os}). \qquad [1]$$

Since $U_f$ is positive, $U_{os}$ must be negative. When full compensation is applied, the output voltage is

$$U_o = U_{tc}R_4/R_1-\gamma T_rR_4/R_2.$$

When $U_{tc}$ is replaced by $E(T_s-T_r)$, this becomes:

$$U_o = ET_sR_4/R_1-T_r(ER_4/R_1+\gamma R_4/R_2) \qquad [2]$$

When this equation is differentiated with respect to $T_s$, R$_4$ can be calculated:

$$dU_o/dT_s = ER_4/R_1 = 1\ \text{mV K}^{-1}$$

from which, if $E$ is given the value 1,

$$R_4 = 24.728R_1. \qquad [3]$$

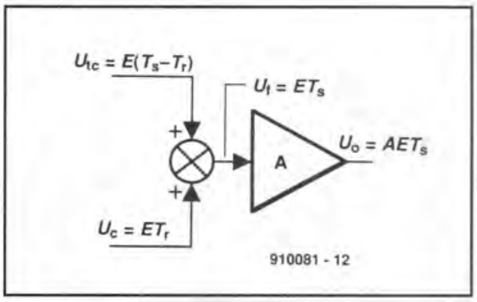


Fig. 2. A compensating voltage that simulates the ice point is added to the thermo e.m.f.

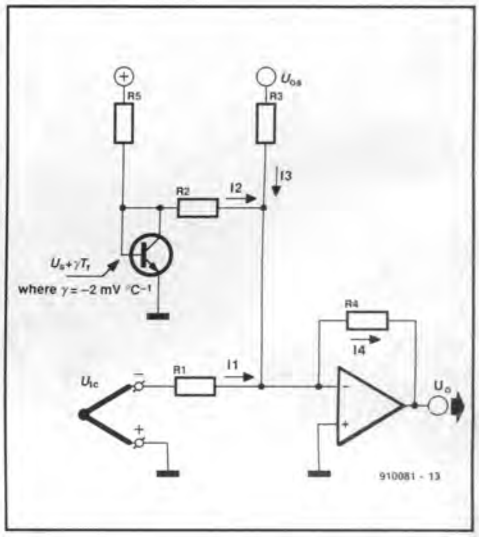


Fig. 3. Input stage of the thermometer.

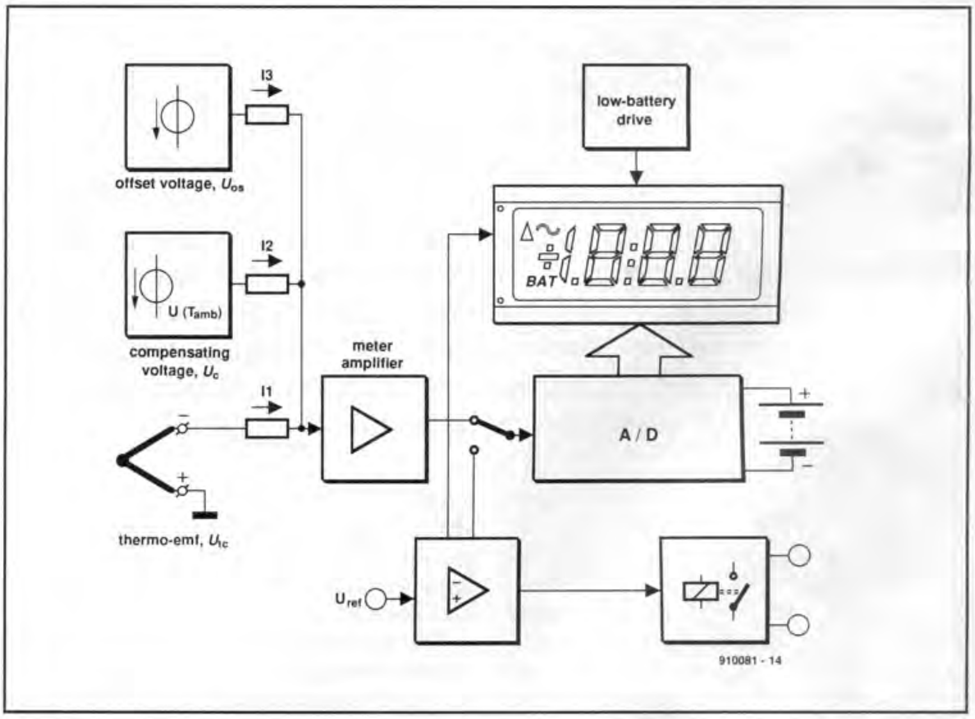


Fig. 4. Block diagram of the thermometer.

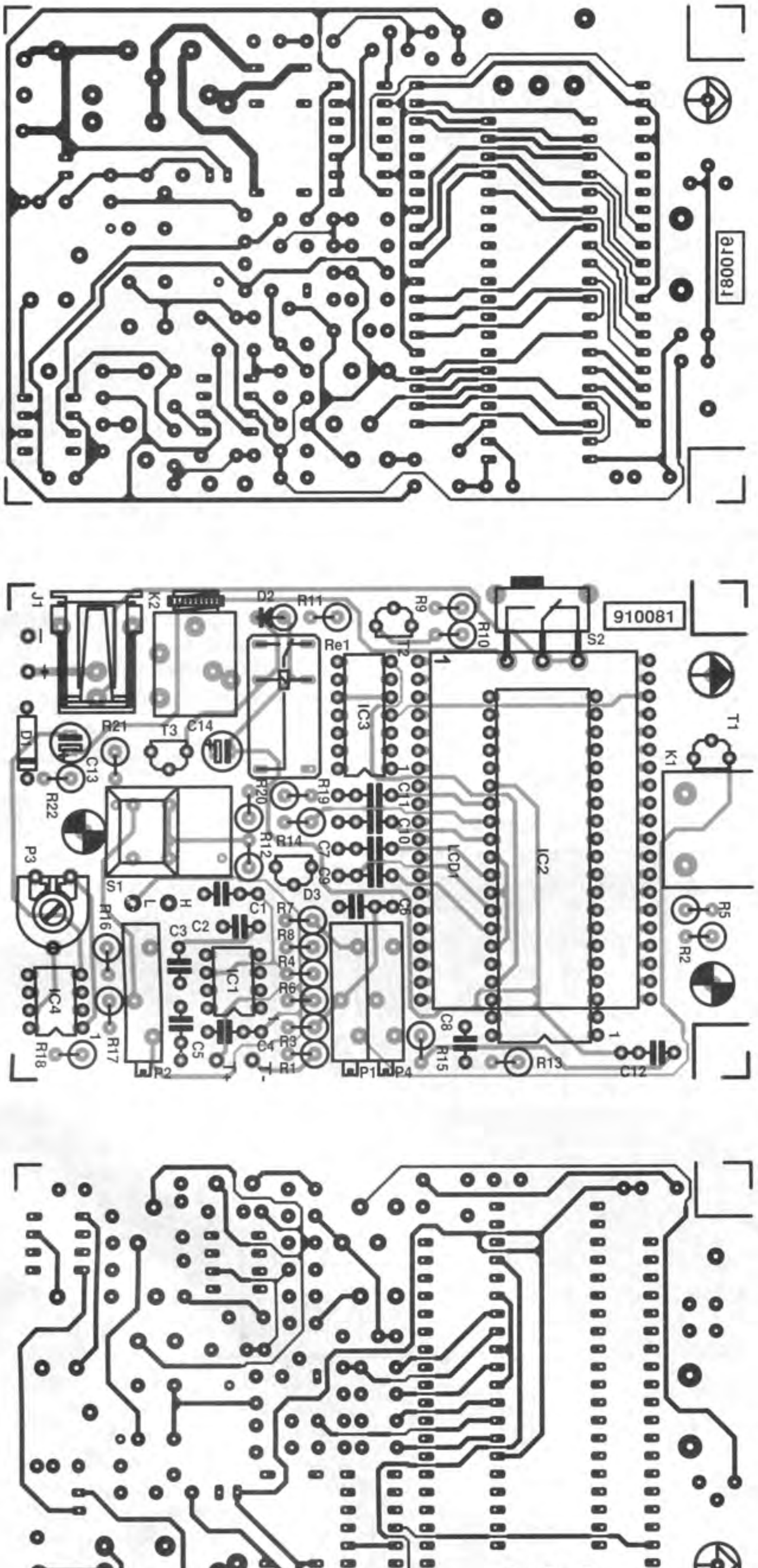


Fig. 5. The double-sided printed-circuit board for the thermometer.

## PARTS LIST

**Resistors:**
R1 = 6.81 kΩ, 1%
R2, R3 = 340 kΩ, 1%
R4 = 169 kΩ
R5 = 1.5 kΩ
R6 = 10 Ω
R7, R12, R17 = 10 kΩ
R8 = 2.7 kΩ
R9, R10 = 1 MΩ
R11 = 330 kΩ
R13, R20, R21 = 100 kΩ
R14 = 475 kΩ, 1%
R15 = 22.1 kΩ, 1%
R16 = 3.3 kΩ
R18 = 10 MΩ
R19 = 220 kΩ
R22 = 220 Ω
P1 = 10 kΩ multiturn preset
P2 = 5 kΩ multiturn preset
P3 = 25 kΩ preset
P4 = 20 kΩ multiturn preset

**Capacitors:**
C1, C6, C12 = 100 nF
C2, C3 = 470 nF, 63 V, MKT*
C4, C5 = 10 nF
C7 = 330 nF
C8 = 100 pF
C9 = 330 nF, 63 V, MKT*
C10 = 47 nF, 63 V, MKT*
C11 = 220 nF, 63 V, MKT*
C13, C14 = 47 µF, 16 V, radial
* MKT = metal-plated polyterephtalate (polyester)

**Semiconductors:**
D1 = 1N4007
D2 = 1N4148
D3 = LM336Z-2.5V (National Semiconductor)
T1, T2 = BC547B
T3 = BC516
IC1 = TLC2652
IC2 = 7106
IC3 = 4030
IC4 = LF356

**Miscellaneous:**
K1 = special socket to be obtained with the thermocouple
K2 = 3.5 mm stereo jack socket for PCB mounting
S1 = spring-loaded push-button switch
S2 = change-over slide switch for PCB mounting
9 V battery with clip
LCD1 = 3 ½ digit display
J1 = low-voltage socket with change-over switch for PCB mounting
Re1 = relay with change-over contact, 5 V, 320 Ω
Enclosure, 145×80×36.5/29.5 mm (5 ¾ × 3 ⅛ × 1 7/16 / 1 3/16 in)
Thermocouple Type K
PCB Type 910081

Equation [2] can also be differentiated with respect to $T_r$:

$$dU_o/dT_r = -(ER_4/R_1+\gamma R_4/R_2) = 0,$$

from which

$$R_2 = -\gamma R_1/E. \qquad [4]$$

Resistor $R_1$ is given an arbitrary value of 6.81 kΩ, so that, according to Eq. [3],

$$R_4 = 24.728\times 6.81\times 10^3 = 168.4\ \text{k}\Omega.$$

The nearest standard value in the E96 series is 169 kΩ.

From Eq. [4],

$$R_2 = -2\times 10^{-3}\times 6.81\times 10^3/40.44\times 10^{-6}$$

$$= 337\ \text{k}\Omega.$$

The nearest standard value in the E96 series is 340 kΩ.

Since, for correct compensation, the levels of $U_f$ and $U_{os}$ must be equal , it follows that

$$R_3 = R_2 = 340\ \text{k}\Omega.$$

The output of the opamp is peak-limited and the device is thus very stable. This means that only a potentiometer is required to calibrate the input stage.

The remainder of the circuit consists of a straightforward analogue-to-digital (A–D) converter that drives the LC display directly. This enables the temperature sensed by the thermocouple to be displayed within a few seconds. A comparator with a relay output is connected in parallel with the display. The relay output can be used for indication or control purposes. Whether the relay is active or not can be seen on the display.

The offset-voltage source provides a constant current through $R_7$, $P_1$, and $R_3$. The preset serves to set the current to a specific value; more about this later. Transistor $T_1$ and the reference ('cold') terminal of the thermocouple must be located close to the offset-voltage source, since they must be thermally coupled. Resistor $R_6$ improves the thermal symmetry of $IC_1$. The output of this opamp is a signal with a voltage-temperature gradient of 1 mV $K^{-1}$.

The A–D converter and the display are straightforward applications. Apart from the 3 ½ digits, only the low BAT(tery) and the triangle at the top left -hand corner are used: the decimal point, colon, and a.c. sign are disabled. When the supply voltage drops below 7.6 V, the BAT input is actuated.

The A–D converter may be powered by a (9 V) battery or regulated mains adapter. If an unregulated adapter is used, the measurement error will increase. The supply should not exceed 15 V under any circumstances, since that will badly affect the operation of the converter. To enable both types of supply to be used, the adapter is connected via a low-voltage socket with change-over contact, $J_1$. On/off switching is effected by $S_2$. Protection against polarity reversal is provided by $D_1$. The reference voltage is determined by potential divider $P_4$–$R_{15}$. When the comparator is inoperative ($P_2$ set to maximum resistance), the circuit draws a current of only a few milliamperes. Note that circuit earth must not be connected to the negative supply line, since the A–D converter needs a small negative auxiliary voltage.

The comparator is based on a Type LF356, which is inexpensive and gives excellent performance even at high synchronous input voltages. When switch $S_1$ is pressed, the inverting input of the comparator is no longer connected to the thermocouple, but to the reference voltage: the display then shows the reference temperature , $T_r$.

The output of the comparator is low when the sensed temperature is higher than that set by potential divider $P_2$–$R_{16}$: the relay is then actuated. The hysteresis of the comparator is set to about 5 kΩ with $R_{17}$ and $R_{18}$.

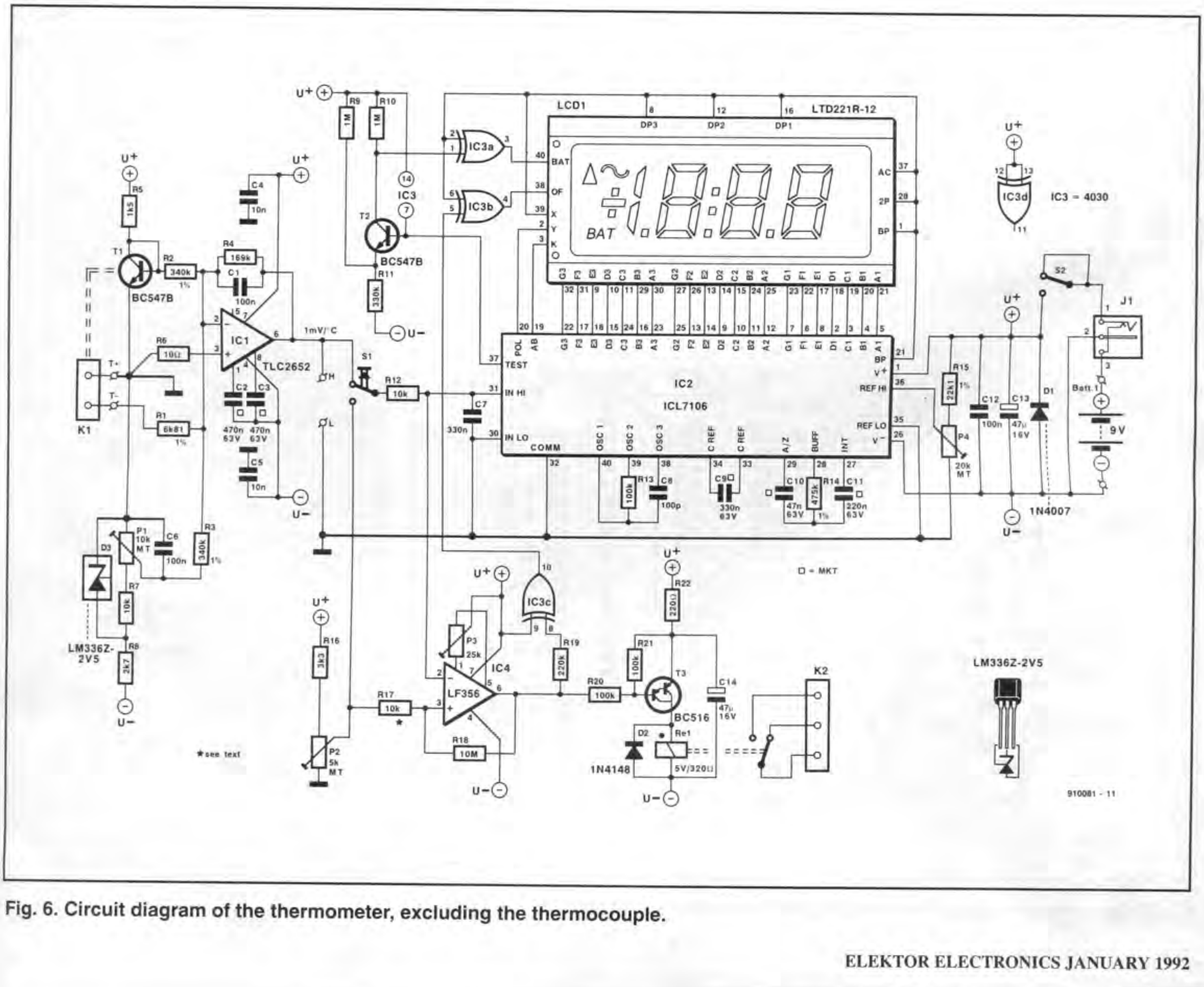


Fig. 6. Circuit diagram of the thermometer, excluding the thermocouple.

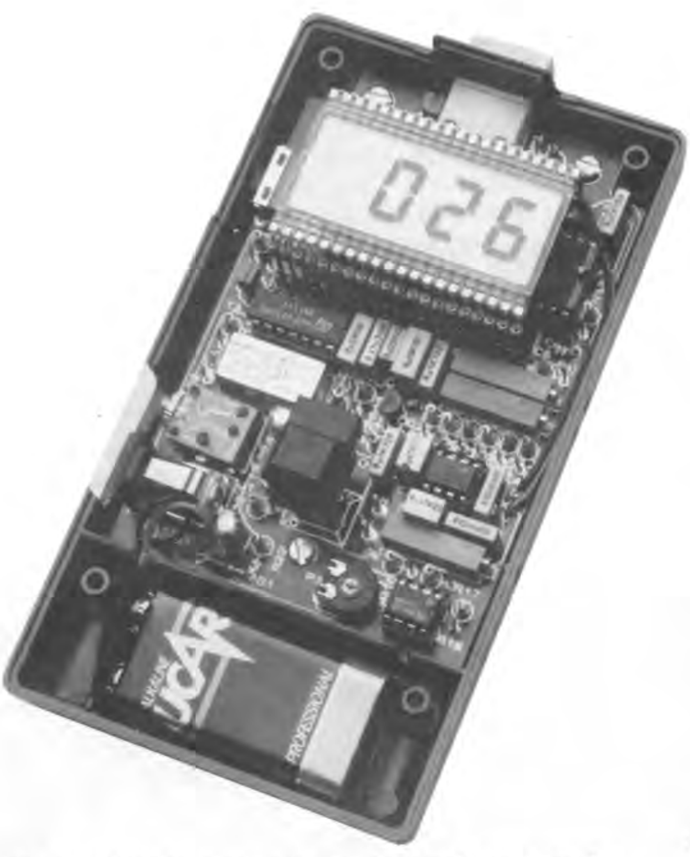


Fig. 7. The completed thermometer, excluding thermocouple.

If the value of $R_{17}$ is lowered to about 1 kΩ, the hysteresis also becomes about 1 kΩ.

A darlington transistor at the output of the comparator controls a polarized relay that is suitable for switching currents of up to 2 A, d.c. voltages of up to 150 V and a.c. voltages of up to 125 V.

When the output of the comparator is low, the output of XOR gate $IC_{3c}$ is high; the output of gate $IC_{3b}$, and thus the OF input of the display, then carries an inverted rectangular signal that causes the triangle on the display to light.

## Construction and calibration

Provided the thermometer is built on the double-sided printed-circuit board shown in Fig. 5, no difficulties should be encountered, in spite of the dense population of the board.

Socket $K_1$ should be purchased together with the thermocouple. Other types, even those for different thermocouples, must not be used, since these will almost certainly cause serious measurement errors.

The finished board and 9 V battery fit in a 140×80×36.5 mm (5 ½ × 3 ⅛ × 1 ⁷⁄₁₆ in) instrument case. This type of enclosure may be available with ready-made cut-outs for the display and slide switch ($S_2$).

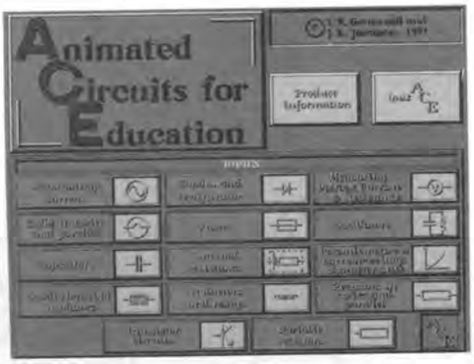
Calibration is commenced by connecting a good-quality mV meter across test points H and L. Then, insert at least ¾ of the length of the thermocouple into boiling water and turn $P_1$ until the meter indicates 100 mV. Next, turn $P_4$ until the display shows 100. Subsequently, press $S_1$ and turn $P_2$ till the meter reads 100 mV and the display shows 100.

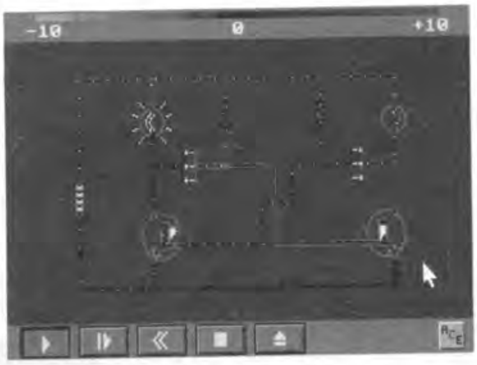
Finally, turn $P_3$ (which compensates for the offset voltage of $IC_4$) until the relay is just actuated and the triangle on the display lights. When that is done, the desired change-over temperature is set with $P_2$ when $S_1$ is pressed. ■

# ANIMATED CIRCUITS FOR EDUCATION

Labcenter Electronics and Bradford Technology have recently released ACE (Animated Circuits for Education), a completely new concept in the teaching of electronics and electricity. The software is aimed at science course pupils in the age range from 11 to 16, although the way ACE brings electric circuits to life will be interesting to many others, including teachers and remedial course students in higher education.

The unique feature of ACE is that it uses a brightly coloured screen to show current flow and voltage difference as they evolve in a wide variety of basic electric circuits. ACE is the perfect introduction into subjects such as parallel connection, series connection, the behaviour of inductors, capacitors, resistors and transistors. Current flow and current direction in the circuits is indicated by moving dots, and voltage by a colour scale. The operation of all circuits can be started, frozen, and speeded up or down at any time by clicking on tape recorder like buttons at the bottom of the screen. So, instead of being confronted with a long circuit description containing lots of next's, if's, and then's, the student has an immediate understanding of what actually happens in a circuit. For instance, he or she can operate a switch, or change the luminous intensity on an LDR, and see the effects instantly on the computer screen.





Topics in the 'curriculum' include switched circuits, conductors and insulators, resistors, voltage, current and resistance measurement, Ohm's law, reactive components, and inductive components. A user manual is supplied containing instructions and a backgrounder to the models used. The minimum hardware requirements to run ACE are an IBM AT class PC or compatible with a 286 processor, 640K RAM, a VGA graphics card, a colour VGA monitor, a Microsoft compatible mouse, a hard disk with 3 MB of free space, and MSDOS 3.00 or later.

ACE is supplied by
**Bradford Technology Ltd. • Ripley Street • Bradford BD5 7RR. Telephone: (0274) 726155. Fax: (0274) 391928.**

# BUILD A COMPACT-DISK PLAYER

by T. Giffard

FRONT COVER PROJECT

**Building a record player, cassette or tape recorder, or compact-disk player, is often hampered by the mechanical construction and the availability of certain parts, particularly the deck. In the past, manufacturers have generally tended to be reluctant to make tape or CD decks available to the retail trade, but Philips has recently decided to break away from this policy. A kit, containing its CDM-4 deck and associated (populated) mother board, can now be obtained from certain retailers at an affordable price.**

PHILIPS's CDM-4 deck, used in a great variety of domestic compact-disk players, has recently become available in the retail trade to enable audio enthusiasts to build their own CD player. The deck comes in a kit complete with a finished mother board, which contains the analogue and digital circuits, and a display board as shown in Fig. 2.

The kit can be used in two ways. The simpler is to build the various items into a suitable enclosure and connect it to a stereo audio system. The second is rather more ambitious and entails the construction of a digital CD driver, that is, a CD player without digital-to-analogue (D–A) converter and other analogue sections. A separate D–A converter can then be used to process the digital output. It is assumed that most audio enthusiasts do not need extensive programming facilities and that good sound reproduction does not require a de-luxe display (the quality of the display is not on a par with that of the deck and the mother board). Since the mother board does not provide a digital output signal, a suitable ancillary circuit and board will be published in a few months' time.

## Construction

When opening the kit, treat the laser unit with respect and care: do not remove the paper clip at end of the packing foil until the laser is required. The unit is very sensitive to static electricity. Also, do not touch its lens, because that may damage the focusing unit.

Mount the disk compartment holder on the board in such a way that the end of the protruding light grey spring-loaded lever is located exactly above the switch at the centre of the board—see Fig. 8. Use only three self-tapping screws at this stage; the fourth, near the compartment switch, is a longer one (to ensure correct operation of the compartment switch) and is not inserted until the assembly is fitted in the enclosure.

Next, fit and solder the transformer on to the board.

Remove the mains (power) socket, fuse holder and on-off switch from the mother board and replace the fuse holder and on/off switch by wire links and the mains (power) socket by a two-way PCB type terminal block. At a later stage, a new mains (power) entry

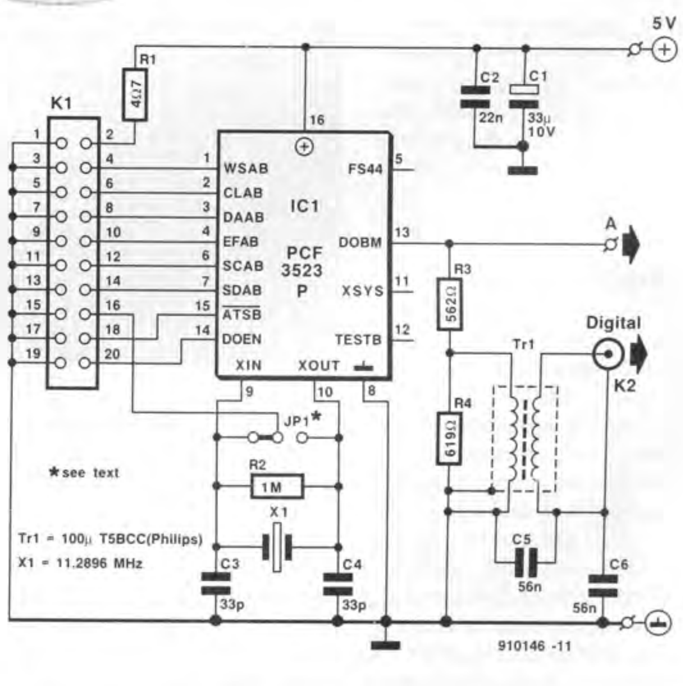


**Fig. 1. Diagram of the auxiliary digital output circuit.**

with integral fuse holder will be fitted at the rear panel of the enclosure.

If you want to use the player as a digital driver only, remove the output (phono) sockets, the D–A converter and the diodes numbered 6580, 6581, 6586 and 6587 (near the left of the heat sink), which disables the entire analogue section.

## Digital output

Some Philips ICs, for instance, the SAA7220B, have a digital output in the filter section, but others, like the SAA7210 used on the present mother board, have not. Therefore, an IC has to be added for converting the digital data into the Philips/Sony format. Suitable for this purpose is the Type PCF3523P Audio Digital Output Circuit. The necessary clock and a number of signals emanating from the SAA7210 are taken from the motherboard via a short length of 20-core flatcable to an auxiliary board, which houses the additional circuitry--see Fig. 16.

Furthermore, a matching transformer is required at the output of the PCF3523P to provide the correct level of output (1 V p-p) and output impedance (75 Ω). The transformer also prevents any earth loops arising between the digital connections of the various pieces of equipment. Capacitors $C_5$ and $C_6$ ensure that the circuit is connected to earth only as far as high-frequency signals are concerned.

Although the auxiliary board has provision for a crystal oscillator, $X_1$, $R_2$, $C_3$ and $C_4$, this is not used in the present application: the clock for $IC_1$ is derived from the mother board via wire link $JP_1$. This proved to give the best results in the present set-up: with other CD players it may be preferable to transfer the crystal from the mother board to the auxiliary board.

The top of the board has an earth plane that serves as screen for high-frequency signals (bandwidth of a couple of megahertz). All components are soldered directly to the board. The housing of the transformer, as well as the –terminal of $C_1$, must be soldered to the earth plane.

The board contains three solder pins that are not used (as yet): these are intended for an optical output (a so-called TOSLINK). It is hoped to publish the details of this addition in a few months' time.

The link between the mother board and the auxiliary board consists of a 30 cm (12 in) length of 20-core flatcable. The cores are soldered to the underside of the mother board as shown in Fig. 14. The details of the various connections are summarized in Table 1.

As far as power is concerned, the +5 V rail is taken from the top of the coil to the left of the SAA7210P. This coil looks like a resistor and is colour-coded yellow-mauve-gold-silver. The earth line is taken from the fairly broad copper track at the underside just beside the +5 V take-off. The two connecting points are indicated by arrows in Fig. 14.

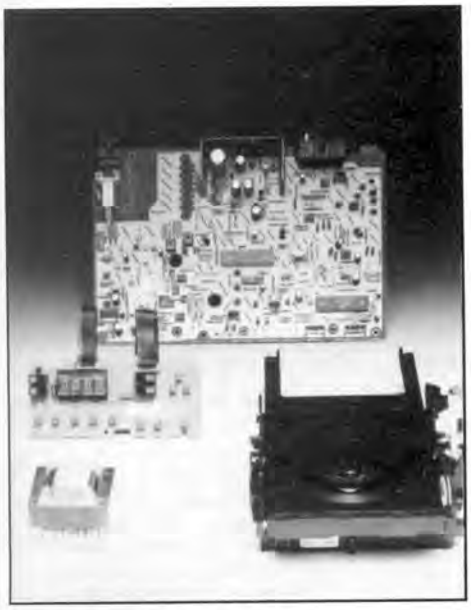


Fig. 2. The kit for the CD player.

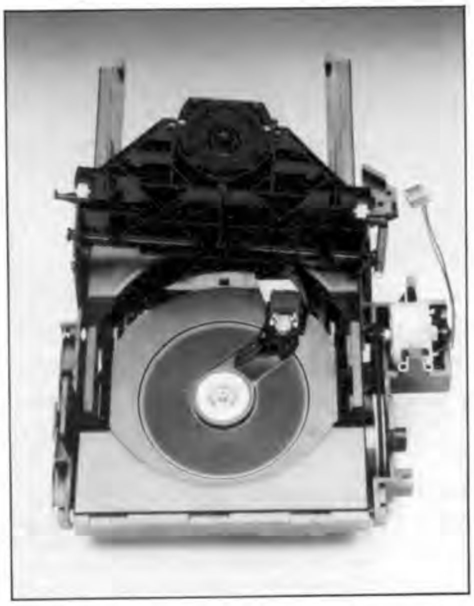


Fig. 3. The assembled CD deck.

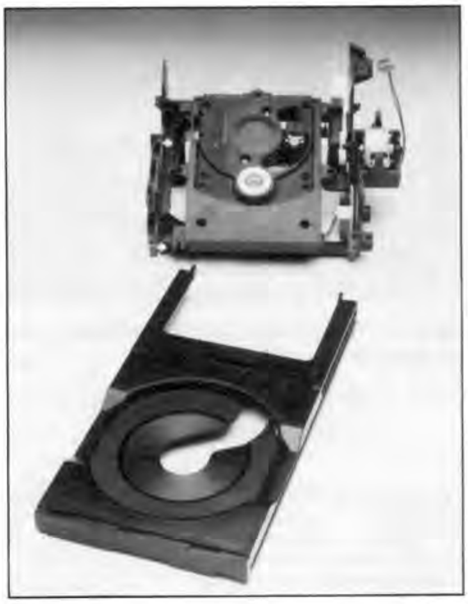


Fig. 4. Disk compartment removed from deck.

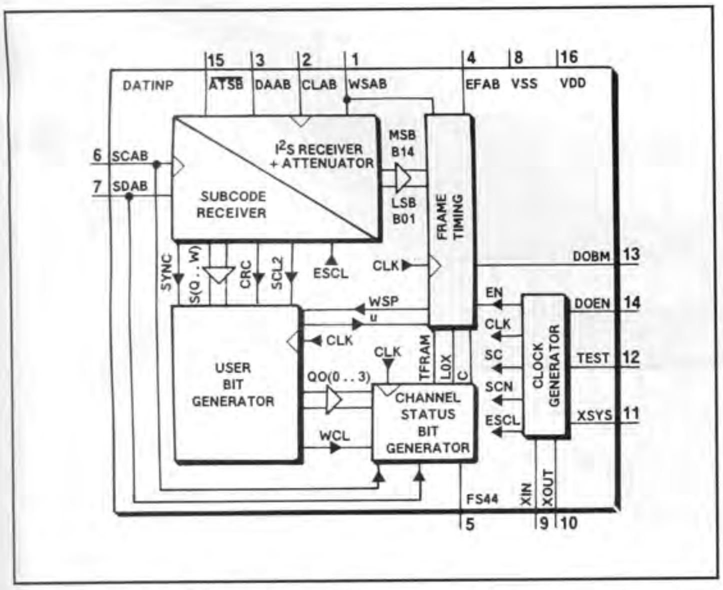


Fig. 5. Pinout and diagram of the PCF3523P.

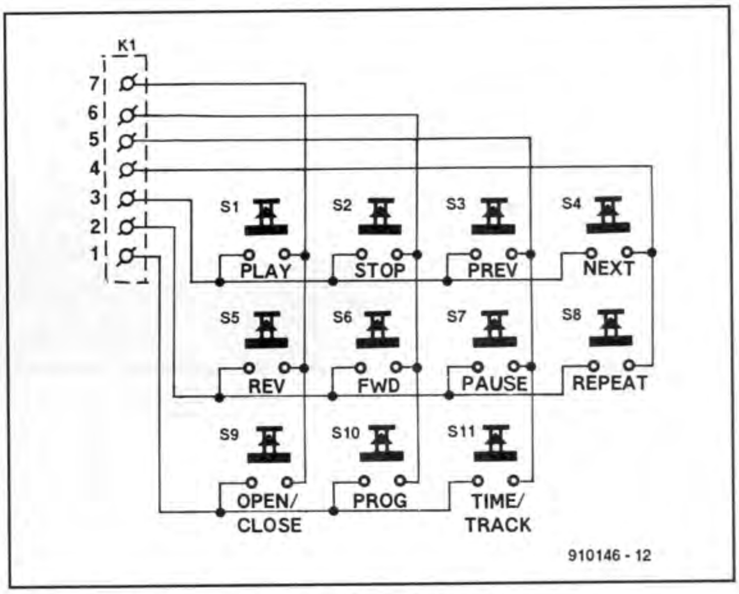


Fig. 6. Diagram of the new key board circuit.

All odd-numbered cable cores, except 1, are cut off at the motherboard: they serve as screen between the various signals.

The other end of the cable is terminated in a crimp-on socket that mates with a plug on the auxiliary board.

Note that the DMUTE signal at pin 17 of the Type XC99659P control processor ensures that the digital output signal is switched off when the player is not revolving or is in the PAUSE position. Some D–A converters do not work properly with this arrangement owing to the time they require to relock on to the signal when this reappears. It may, therefore, be better not to use the DMUTE signal by leaving core 20 unconnected.

## Display and operating keys

The display board, part of the board shown in Fig. 16, is linked to the mother board by two flatcables: the six-core one carries the data from the control processor to the display and the four indicator LEDs, and the seven-core one connects the matrix to the keys. Since the keys provided in the kit are not suitable for a DIY apparatus, they have been replaced by miniature key switches that are mounted on to the key board.

Note that the board in Fig. 16 can be easily separated into two as shown in Fig. 15 after it has been scored at the separation line with a sharp knife. Drill an additional fixing hole in the display board.

Desolder the seven-core cable from the board: at a later stage it will be connected to the new key board. Also, remove the four LEDs and their square holders: these will be replaced by high-efficiency LEDs.

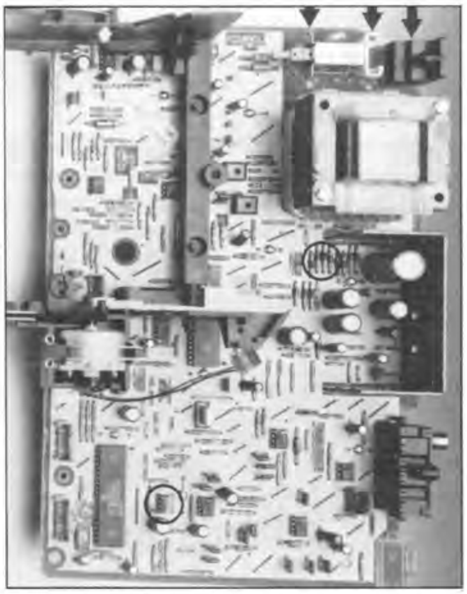


**Fig. 7. Some items must be removed from the mother board.**

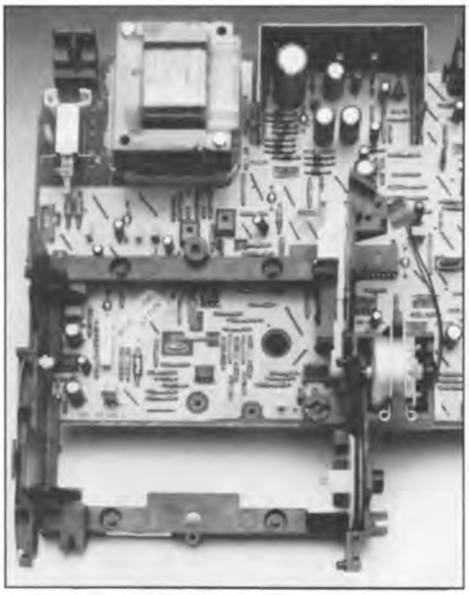


**Fig. 8. Disk compartment holder and mains transformer on mother board.**

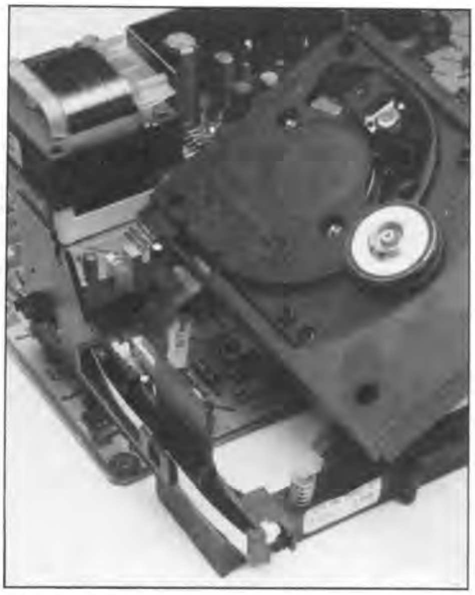
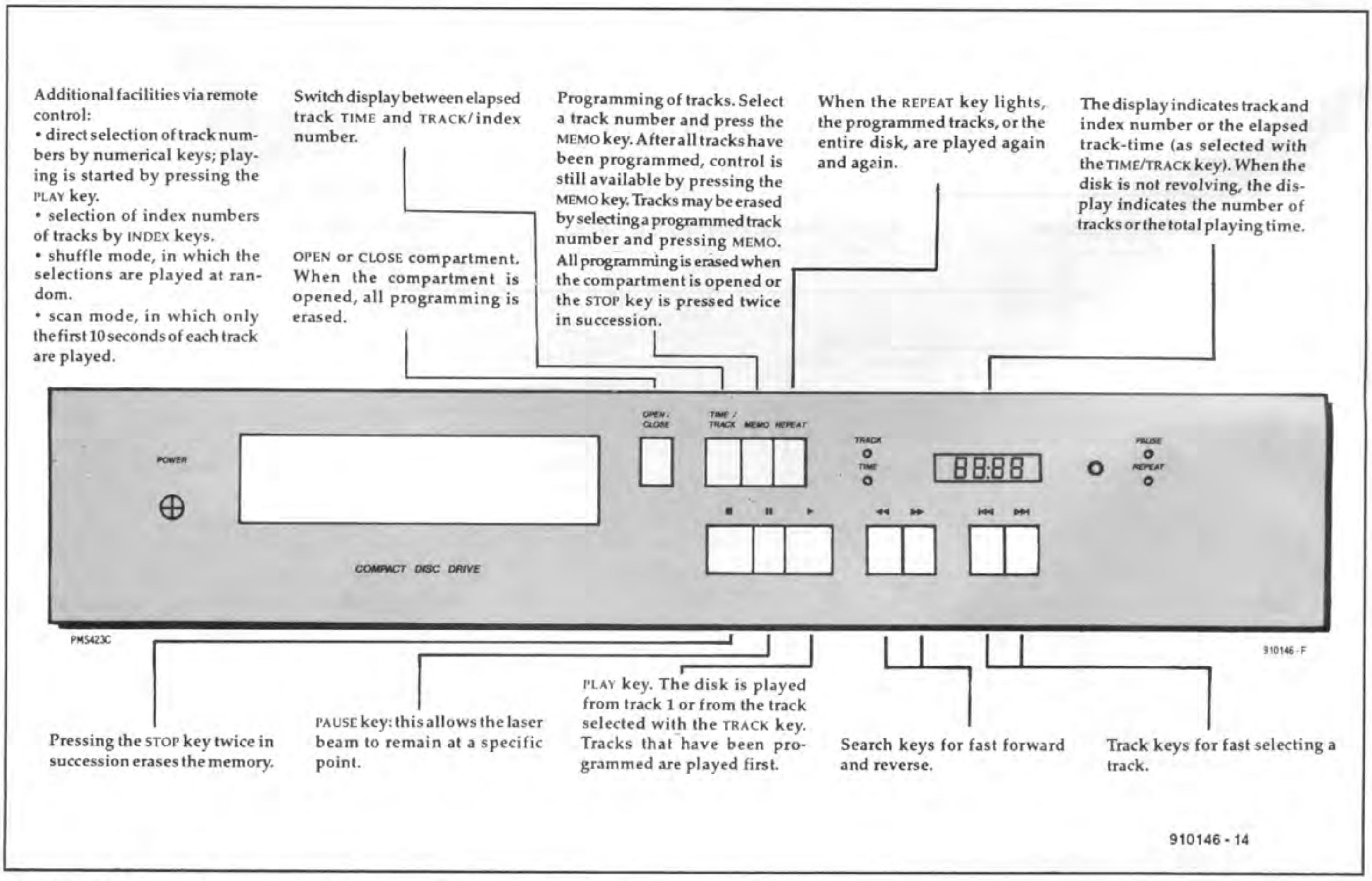


**Fig. 9. Laser unit connected to mother board.**



Additional facilities via remote control:
- direct selection of track numbers by numerical keys; playing is started by pressing the PLAY key.
- selection of index numbers of tracks by INDEX keys.
- shuffle mode, in which the selections are played at random.
- scan mode, in which only the first 10 seconds of each track are played.

Switch display between elapsed track TIME and TRACK/index number.

OPEN or CLOSE compartment. When the compartment is opened, all programming is erased.

Programming of tracks. Select a track number and press the MEMO key. After all tracks have been programmed, control is still available by pressing the MEMO key. Tracks may be erased by selecting a programmed track number and pressing MEMO. All programming is erased when the compartment is opened or the STOP key is pressed twice in succession.

When the REPEAT key lights, the programmed tracks, or the entire disk, are played again and again.

The display indicates track and index number or the elapsed track-time (as selected with the TIME/TRACK key). When the disk is not revolving, the display indicates the number of tracks or the total playing time.

Pressing the STOP key twice in succession erases the memory.

PAUSE key: this allows the laser beam to remain at a specific point.

PLAY key. The disk is played from track 1 or from the track selected with the TRACK key. Tracks that have been programmed are played first.

Search keys for fast forward and reverse.

Track keys for fast selecting a track.

**Fig. 10. Front panel and concise operating instructions.**

The display board has space (to the right of the display) for an infra-red (IR) remote control receiver: an option that is strongly recommended. Sony's Type BX1407 is particularly suitable; Sharp's GP1U5 can also be used, but this has slightly different connections. Finally, two resistors, 22 kΩ and 3.3 Ω respectively, must be added as shown in Fig. 17. This arrangement will allow remote control of the player by any Philips IR transmitter intended for CD players (such as the Type RD5861).

Completion of the key board, whose 'circuit diagram' is given in Fig. 6, is straightforward. Keys of varying width have been used to make operation unambiguous.

Lastly, solder the seven-core cable removed from the display board to the key board: keep the white line on the cable at the side of pin 7 on the board.

## Assembly

First, drill, saw and file the necessary holes in the enclosure: use the front panel foil and the front panel of the disk compartment for accurate location of the holes in the front panel and Fig. 13 for those in the bottom panel. Do not forget the holes in the back panel: mains (power) socket with integral fuse holder (at the left seen from the front panel); digital output (at the right); and phono sock-

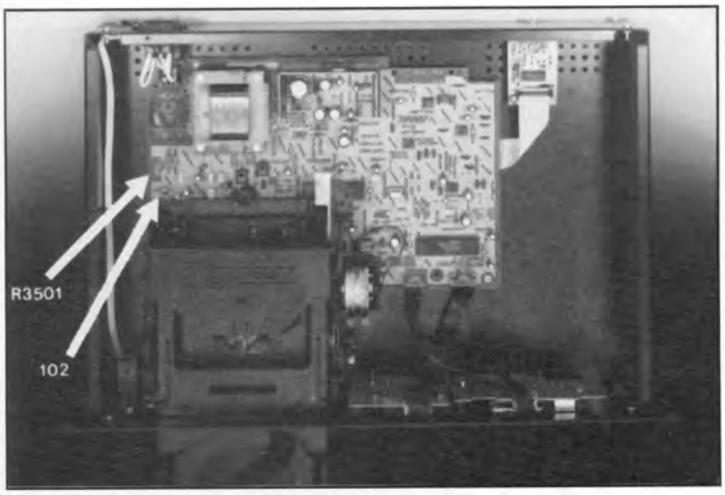


Fig. 11. The completed CD player.

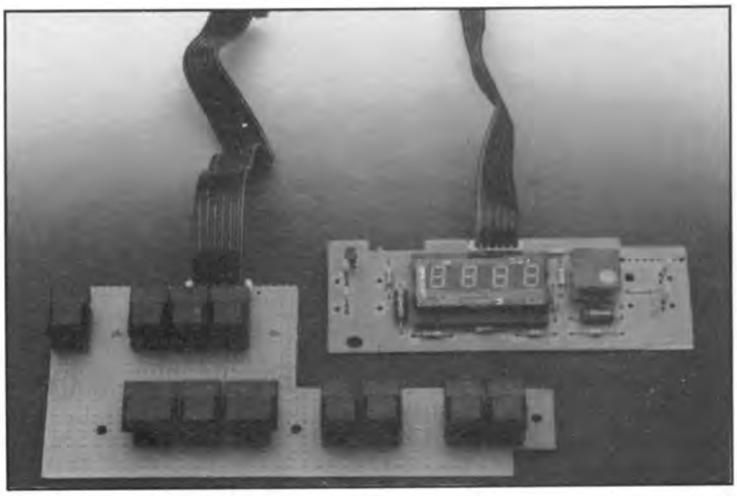


Fig. 12. Completed display and key boards.

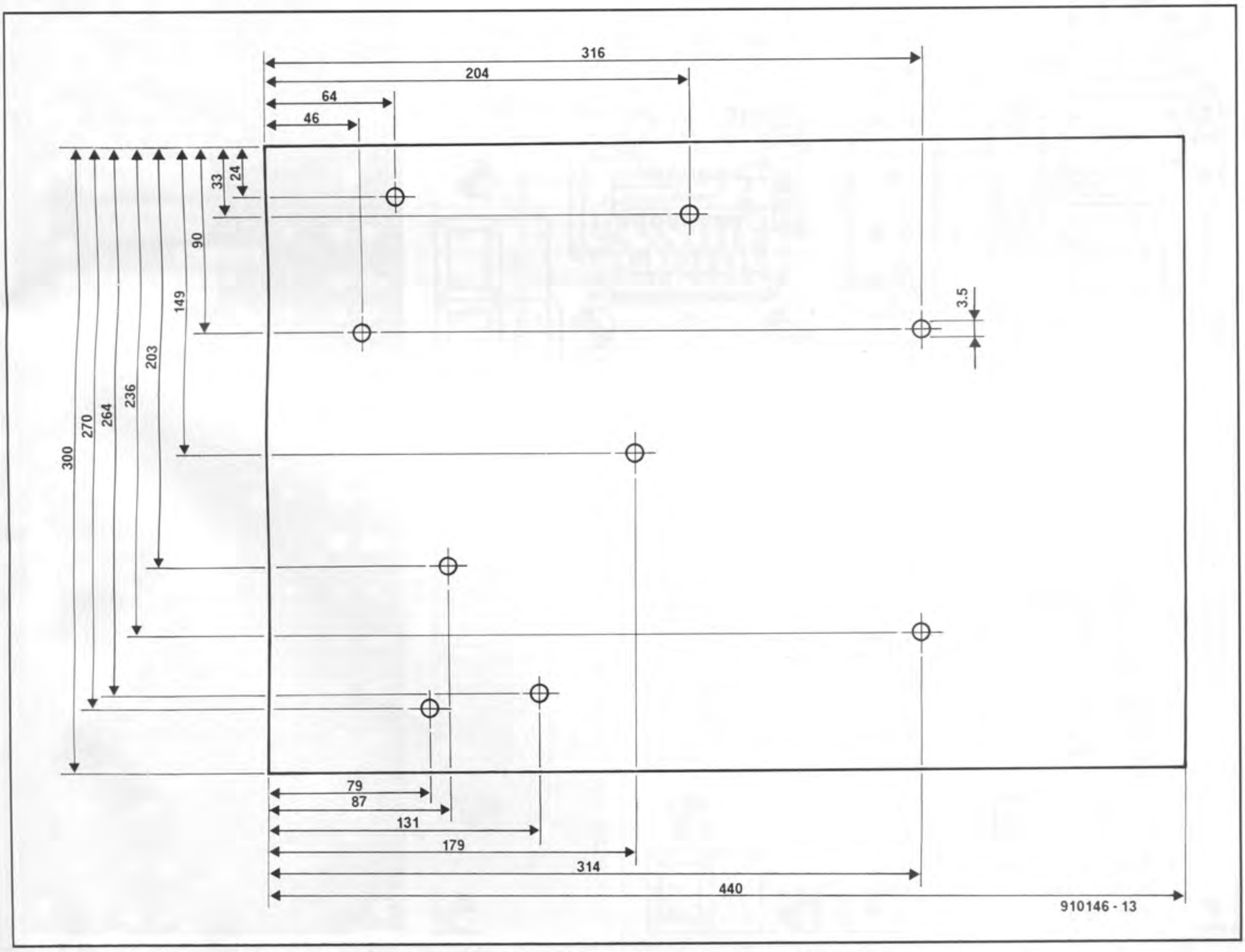


Fig. 13. Drilling diagram for the bottom panel of the enclosure. All dimensions are in mm.

ets if you want to use analogue outputs.

Mount the key board and the display board to the front panel with, respectively, five and two 25 mm (1 in) long M3 (=6BA=3 mm dia.) countersunk screws, nuts and washers. The key board should be located so that the keys protrude just far enough through the front panel. Next, fasten the self-adhesive front panel foil to the front panel.

Fix the mother board to the bottom panel on 10 mm (⅜ in) long non-metallic spacers: the location of the fixing holes is shown in Fig. 13. Do not omit the central fixing screw, because that ensures correct operation of the disk compartment switch. Fit two M3 screws

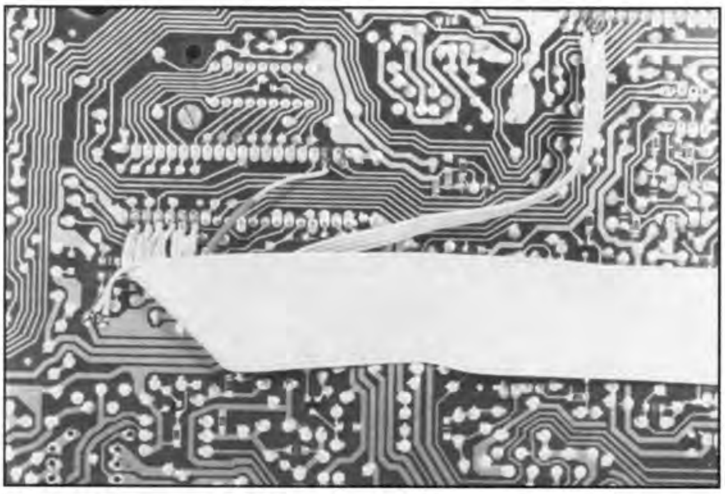


Fig. 14. How to connect the flatcable to the underside of the mother board.

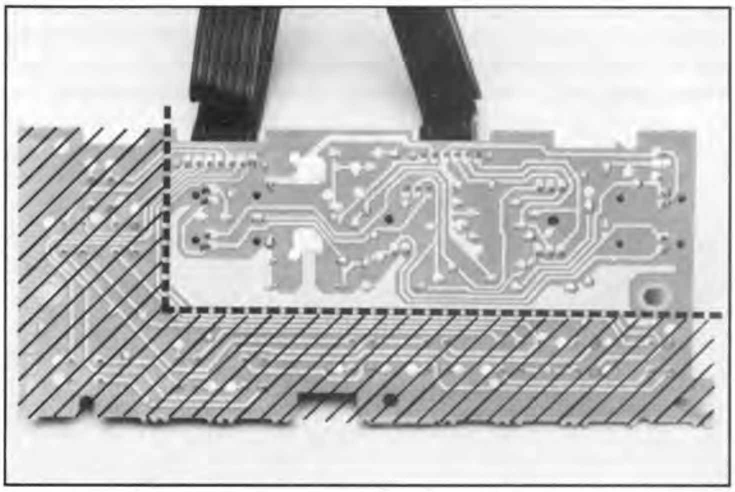


Fig. 15. How to separate the board shown in Fig. 16 into two.

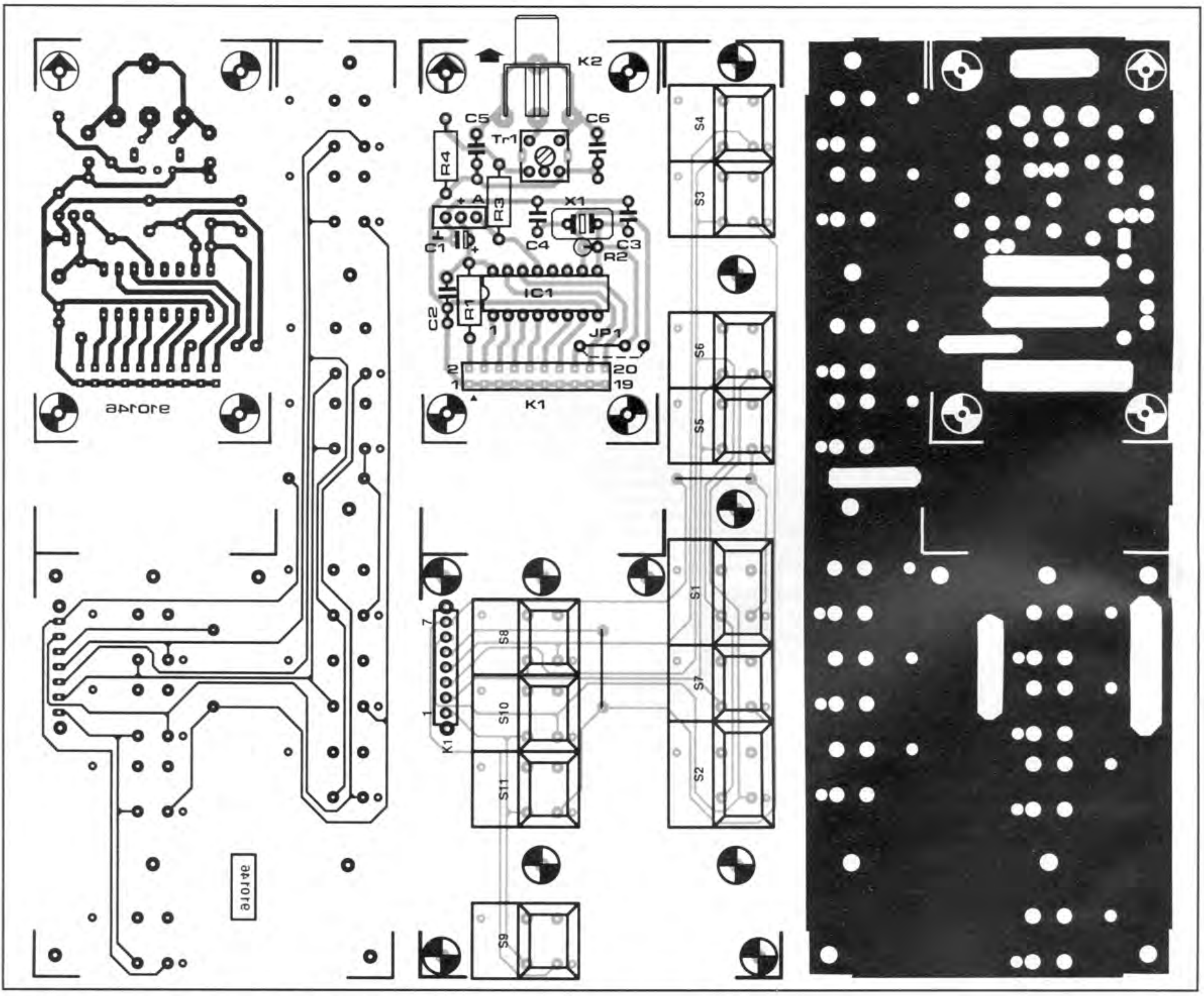


Fig. 16. The combined auxiliary (digital output) and key boards.

with 35 mm (1 ⅜ in) non-metallic spacers to the left and right of the disk compartment. The transformer is fastened with two M4 (=4BA=4 mm dia.) screws that pass through the board, two non-metallic spacers, and the bottom panel, where nuts and washers are attached.

## PARTS LIST

### Auxiliary board

**Resistors**:
R1 = 4.7 Ω
R2 = 1 MΩ
R3 = 562 Ω, 1%
R4 = 619 Ω, 1%

**Capacitors**:
C1 = 33 μF, 10 V, tantalum
C2 = 22 nF, ceramic
C3, C4 = not used
C5, C6 = 56 nF

**Semiconductors**:
IC1 = PCF3523P

**Miscellaneous**:
K1 = 20-way header, male
K2 = right-angled phono socket
X1 = not used
Tr1 = matching transformer (Philips Type T5BCC)

### Key board

S1, S2 = keyboard switch, 17 mm wide, with keytop
S3–S12 = keyboard switch, 12 mm wide, with keytop

### Miscellaneous

4× LED, yellow, 3 mm (high efficiency)
DPDT mains (power) switch
Mains (power) plug, panel mounting, with integral fuse holder
Fuse, 50 mA, delayed action
Enclosure, 19 in (483 mm) wide, 2 units high, 12 in (30 cm) deep
PCB 910146
Front panel foil 910146F

### Remote control

1× resistor, 3.3 Ω
1× resistor, 22 kΩ
1× IR receiver, Sony BX1407

Mount the auxiliary board at the right-hand side of the enclosure on non-metallic spacers so that the output socket protrudes through the back panel.

Wire up the mains (power) section.

Solder the flatcables from the display board and the key board to the mother board.

Fit the new three-way connector to the two wires from the CD motor: black to pin 1, and brown to pin 2.

Unlatch the flexfoil connector on the mother board by pulling it up slightly and place the laser unit at right angles to it so that the flexfoil is immediately above it. Carefully remove the paperclip from the end, place the flexfoil into the connector, and press the latch down to fasten the two together.

Place the springs and rubber grommets as shown in Fig. 9, hook the two left-hand clips of the laser unit into the deck and carefully press down and inwards the clip at the right-hand back of the unit.

Insert the motor connector to the associated connector on the mother board (immediately adjacent to the light-grey lever of the compartment switch. Link the three-way motor connector to the three-way connector to the right of the deck.

Finally, place the pressure plate and associated spring on to the disk-compartment and push the whole into the deck. Clip the lid of the compartment into place at the front.

The kit also contains a headphone socket that may be connected, if desired, to the free connector at the right-hand side of the mother board. If this is used, the entire analogue section must be left intact. The socket is linked to the board by three wires: centre pin to centre pin, the terminal closest to the front of the socket to the right-hand pin of the connector on the board, and so on. Note that there is no volume control for the headphone output.

DO NOT YET connect the mains (power) supply.

## Calibrating the deck

To prevent too high a current through the laser, set the 4.7 kΩ preset on the mother board behind the deck to a value of about 800 Ω, measured with a multimeter connected between its centre and right-hand terminals. Set the adjacent 22 kΩ preset to the centre of its travel.

Connect the mains (power) supply to the unit.

Warning: DO NOT LOOK into the laser, after the mains (power) has been switched on, because that could cause permanent eye damage.

Lift the pressure plate of the deck and switch on the mains (power) supply. If all is in order, the laser arm should move inwards, and the laser lens should briefly move up and down. Also, the CD motor should move briefly and slightly. If these do not happen, switch off and check that the flexfoil is fastened securely in the appropriate connector. Laser operation can also be checked visually. Standing in front of the player, look at the laser lens at an angle of 20–30°. When the mains (power) is switched on, a red reflection should be visible at the edge of the lens for a few seconds.

Connect a multimeter (100 mV range) across $R_{3501}$ (4.7 kΩ at the left behind the deck at the edge of the board, just in front where the mains switch used to be). Adjust the 4.7 kΩ preset on the mother board behind the deck for a meter reading of 50 mV. Take care not to turn the preset too far to prevent too high a current through the laser.

Connect the multimeter (1 V d.c. range) between wire link 102 and the earth plane. Insert a CD, preferably one with standardized reflection, and switch on the player. While selection 1 is played, adjust the 22 kΩ preset (immediately adjacent to the 4.7 kΩ preset) for a meter reading of 400 mV d.c.

This completes the calibration.

## Finally

It is advisable to stick some self-adhesive bituminous felt to the inside of the top panel of the player to prevent any vibrations arising in the panel.

Concise operating instructions, incl. those with a remote control unit, are given in Fig. 10. ■

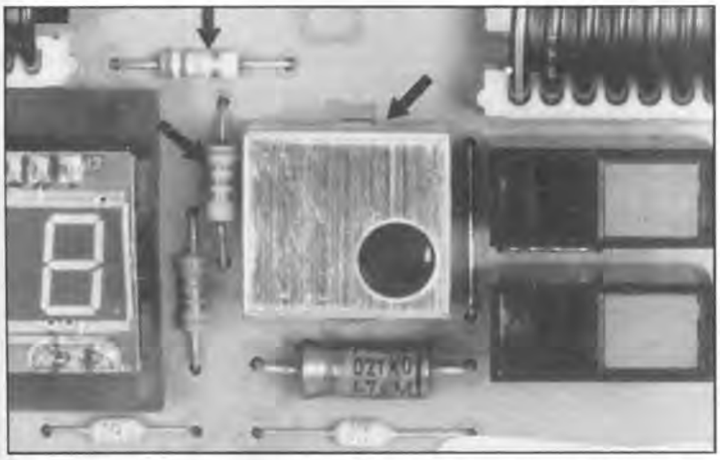


Fig. 17. Where to fit the IR receiver and extra resistors (arrowed).

**Table of connections**

| Core no. | Connected to on mother board |
|---|---|
| 1 | earth (beside +5 V connection |
| 2 | +5 V (top of inductor 5501) |
| 4 | pin 39 of SAA7210P (WSAB) |
| 6 | pin 38 of SAA7210P (CLAB) |
| 8 | pin 37 of SAA7210P (DAAB) |
| 10 | pin 36 of SAA7210P (EFAB) |
| 12 | pin 35 of SAA7210P (SCAB) |
| 14 | pin 34 of SAA7210P (SDAB) |
| 16 | pin 8 of SAA7210P (XOUT) |
| 18 | pin 18 of XC99659P (ATSB) |
| 20 | pin 17 of XC99659P (DMUTE) |

# LOW-FREQUENCY COUNTER

by F. Hueber

**The frequency counter described in this article may be built into an existing apparatus or be used as a stand-alone unit. It obviates the problem of every frequency counter – the accurate calibration of the time base – by ingenious circuit design.**

A FREQUENCY counter is indispensable in the design, repair and test of audio and hi-fi equipment. The counter presented here can either be built into a sine wave or function generator or, by the addition of a preamplifier, power supply and a suitable enclosure, be made into a stand-alone unit. Its display has only four digits, since three or four of the usual seven or eight display digits are not used in audio work. Three switched measuring ranges are provided: 0–1000 Hz; 0–10 kHz; and 0–100 kHz.

## Counter circuit

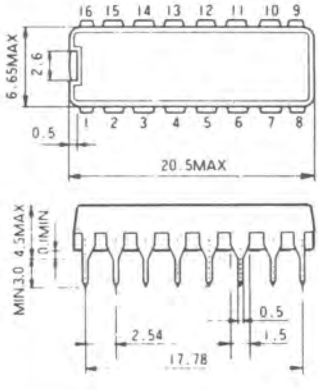
The heart of the circuit—see Fig. 4—is $IC_1$, a TTL-compatible CMOS IC Type 74C925 from National Semiconductor. Housed in a 16-pin DIL package, this device contains four decade counters, a status memory, a multiplexer, and a seven-segment decoder for a four-digit display. The common-cathode, seven-segment display, $LD_1$–$LD_4$, is driven by transistors $T_1$–$T_4$. The segments of the four digits are fed in parallel via limiting resistors $R_1$–$R_7$.

Transistor $T_5$ ensures that the decimal point is switched in tandem with the metering ranges. It is cut off by the display drivers via $D_1$ when $S_{1b}$ is in the relevant position: the decimal point then lights. To make certain that the transistor switches off promptly, it must be a germanium or Schottky type: the base-emitter potential of a standard silicon diode remains too high.

To prevent any problems with the calibration of the time base, it was decided to clock it by a Type SPG8650B ($IC_3$) from Seiko-Epson. This standard pulse generator, whose pinout is given in Fig. 1, contains a hybrid circuit consisting of a quartz oscillator and two programmable dividers that, depending on the bit sample at input pins 2–7, provides 57 discrete output frequencies. The fundamental frequency is 100 kHz, and the frequency tolerance is 50 p.p.m.

The necessary pull-down resistors for the programming inputs have been integrated in the IC, so that all open inputs pins are automatically at earth potential (logic 0). Apart from programming switch $S_{1a}$, no other external parts are required.

When pins 3 and 7 are high (logic 1), output pin 9 provides a signal of 5 Hz; when pin 5 is high at the same time, the frequency of the signal is 0.5 Hz; when pins 3, 6 and 7 are high, the frequency of the signal is 0.05 Hz. The corresponding gate times of the counter are 100 ms (0–99.99 kHz range); 1 s (0–9.999 kHz range); and 10 s (0–999.9 Hz range). All available combinations are given in Fig. 2.



1. NC
2. CTL3
3. CTL2
4. CTL1
5. CTL6
6. CTL5
7. CTL4
8. $V_{SS}$
16. $V_{DD}$
15. NC
14. RESET
13. NC(CSEL)
12. NC(EXC)
11. FOUT
10. TEST
9. OUT

NC: Not connected

910149-13

Fig. 1. Pinout of the SPG8650B.

**8650B 8651B**

| SETTING | | CTL4 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CTL5 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| CTL1 | CTL2 | CTL3 \ CTL6 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| 0 | 0 | 0 | 100K | 10 K | 1K | 100 | 10 | 1 | 1/10 | 1/100 |
| 0 | 0 | 1 | 10K | 1 K | 100 | 10 | 1 | 1/10 | 1/100 | 1/1000 |
| 0 | 1 | 0 | 50K | 5 K | 500 | 50 | 5 | 1/2 | 1/20 | 1/200 |
| 0 | 1 | 1 | 33.3K | 3.3K | 333.3 | 33.3 | 3.33 | 1/3 | 1/30 | 1/300 |
| 1 | 0 | 0 | 25K | 2.5K | 250 | 25 | 2.5 | 1/4 | 1/40 | 1/400 |
| 1 | 0 | 1 | 20K | 2 K | 200 | 20 | 2 | 1/5 | 1/50 | 1/500 |
| 1 | 1 | 0 | 16.6K | 1.6K | 166.6 | 16.6 | 1.6 | 1/6 | 1/60 | 1/600 |
| 1 | 1 | 1 | 8.3K | 833.3 | 83.3 | 8.3 | 0.83 | 1/12 | 1/120 | 1/1200 |

910149 – 14

Fig. 2. Programming possibilities of the SPG8650B.

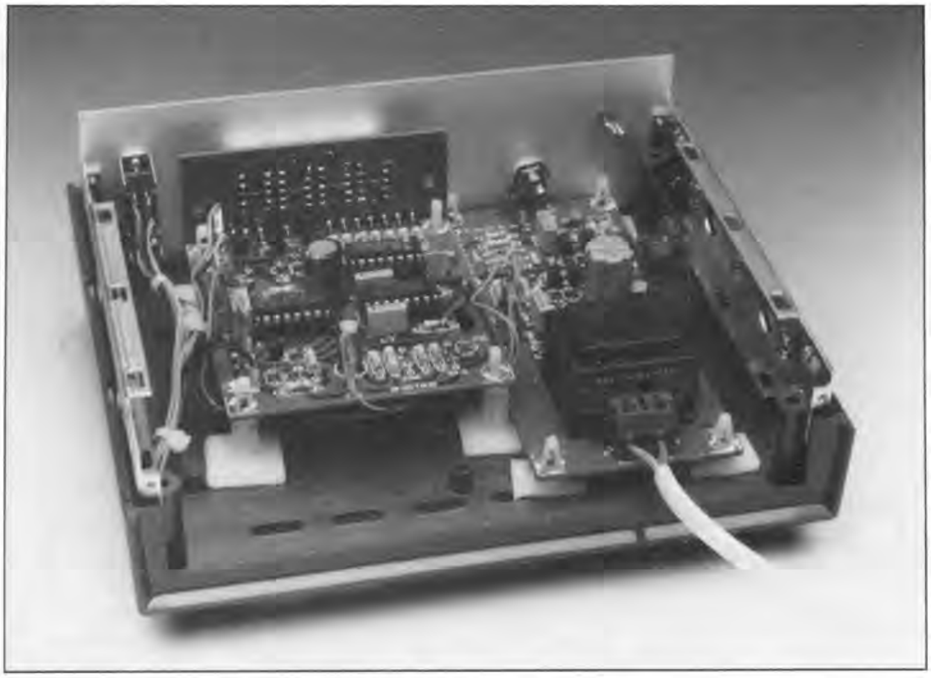


Fig. 3. Rear view of the counter with top panel removed.

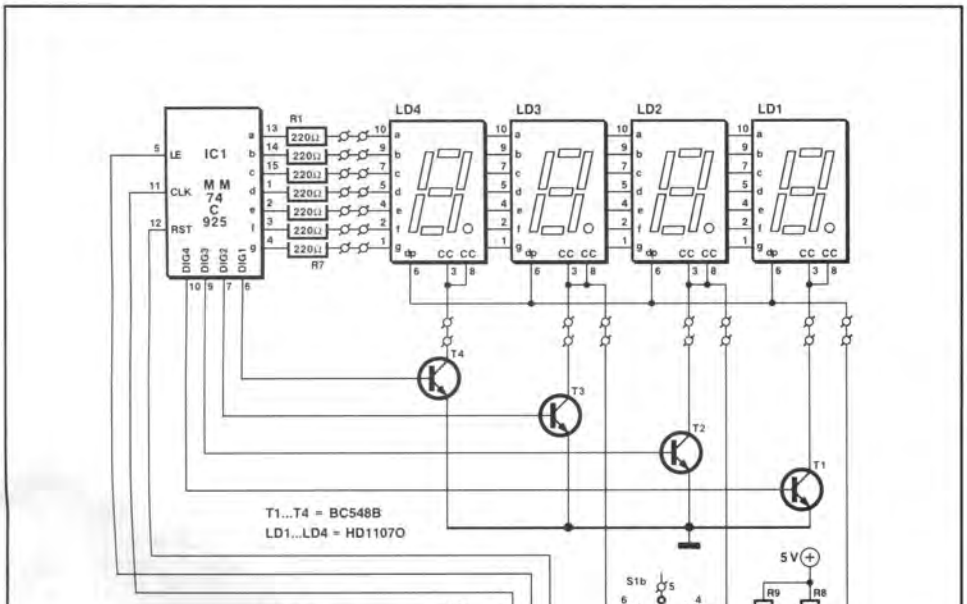


Fig. 4. Diagram of the counter circuit.

Since $IC_3$ provides an output pulse with a duty factor of 1:1, and $IC_1$ counts only when that output is high, a count period is twice as long as the pulse duration. With 100 ms and 1 s gate times, that does not matter much, but when the gate time is 10 s, there is a delay of 20 s between two consecutive displays. A little patience is, therefore, required during measurements, but that is rewarded by a resolution of 0.5 Hz, which, particularly at low frequencies, is extremely useful.

The exact state of the counter is indicated by a gate display consisting of $T_7$ and $D_5$. Owing to the tiny base current through $R_{16}$, transistor $T_7$ must be a type with high current amplification. The value of $R_{16}$ cannot be reduced, since the maximum permissible current drawn from pin 9 of $IC_3$ is 40 µA. If the high resolution is of no interest, the gate display can be omitted and $S_1$ can be a simple 2-pole change-over switch.

To function correctly, $IC_1$ needs a latch pulse and a reset pulse, which are provided by monostables $IC_{2a}$ and $IC_{2b}$ respectively. The last transition (trailing edge) of the gate-time pulses triggers $IC_{2a}$, which causes a pulse of about 7 µs at the latch input (LE) of $IC_1$, whereupon the counter content is shifted into the display memory. The last transition of the 7 µs pulse triggers $IC_{2b}$, whose output resets the counter.

Buffer $T_6$ prevents the clock input of the counter accepting too high values.

The input pulses and gate-time pulses are combined by 'OR gate' $D_2$–$D_3$–$R_{12}$.

The level of the input signal to the counter should be not lower than 2 V r.m.s.: for lower levels, a simple preamplifier—see Fig. 5—is needed. The level may be as high as 100 V, provided that the working voltage of $C_3$ allows this.

The +5 V power supply must be regulated; the maximum current drawn from it is only 80 mA.

## Preamplifier and power supply

The preamplifier, needed when input levels <2 V are processed, and the power supply, whose circuits are shown in Fig. 5, are built on to a small PCB (Fig. 8).

The preamplifier is designed around discrete components. FET $T_{10}$ functions as impedance converter to provide the necessary high input impedance. Resistor $R_{21}$ and anti-parallel connected diodes $D_{10}$ and $D_{11}$ form a protection network that limits the gate voltage of $T_{10}$ to about 700 mV, although the input level may be as high as 100 V.

The input impedance for input levels <600 mV r.m.s. is about 1 MΩ, that is, the value of $R_{20}$. At higher inputs, the impedance drops, because $D_{10}$ and $D_{11}$ then conduct, thereby shunting $R_{20}$ with $R_{21}$. At inputs of 1 V r.m.s., the input impedance is about 400 kΩ and at 2 V r.m.s. it is about 150 kΩ. If that is too low, the value of $R_{21}$ can be increased up to 1 MΩ. Unfortunately, owing to the unavoidable capacitance of the diodes and the FET, the input sensitivity for frequencies >10 kHz then deteriorates by up to 14 dB.

## PARTS LIST

**Resistors**:
R1–R7 = 220 Ω
R8 = 390 Ω
R9, R27 = 47 kΩ
R10, R11 = 10 kΩ
R12 = 3.3 kΩ
R13, R22 = 1 kΩ
R14, R23 = 100 kΩ
R15 = 22 kΩ
R16, R21 = 150 kΩ
R17 = 470 Ω
R20 = 1 MΩ
R24, R30 = 5.6 kΩ
R25, R26 = 1.8 kΩ
R28 = 560 Ω
R29 = 8.2 kΩ
P1 = 100 kΩ multiturn preset, vertical

**Capacitors**:
C1, C2 = 1 nF
C3 = 10 μF, 35 V, vertical
C4 = 330 nF
C5 = 220 μF, 10 V, vertical
C6, C14 = 100 nF, ceramic
C10 = 150 nF, 250 V
C11, C12 = 4.7 μF, 35 V, tantalum
C13 = 270 pF
C15 = 10 μF, 10 V, vertical
C16 = 470 μF, 25 V, vertical

**Semiconductors**:
D1 = BAT85
D2–D4, D10, D11 = 1N4148
D5 = LED, 3 mm
D12–D15 = 1N4001
T1–T5, T11–T13 = BC548B
T6 = BC558B
T7 = BC548C
T10 = BF245C
IC1 = MM74C925
IC2 = 74LS221
IC4 = 7805

**Miscellaneous**:
S1 = 2 pole, 3 position slide switch
K1 = phono socket
K2 = 2-way terminal block (mains) for PCB mounting
LD1–LD4 = 4-digit, 7-segment display
Tr1 = mains transformer, 9 V, 1.5 VA rating
Enclosure 60×150×132 mm (2 3/8 × 5 7/8 × 5 3/16 in)
PCB 910149-1
PCB 910149-2

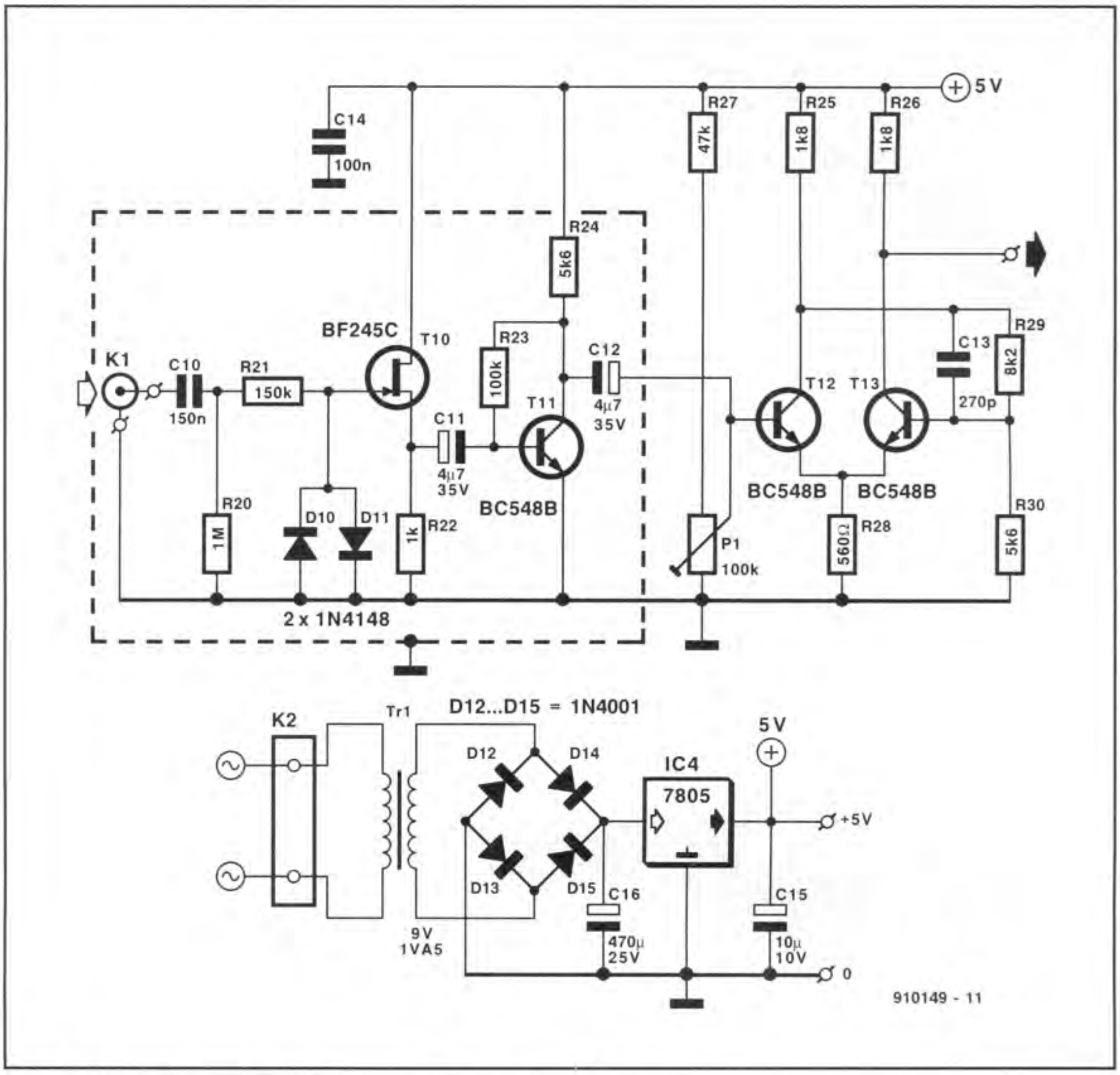


Fig. 5. Circuit diagram of the preamplifier and power supply.

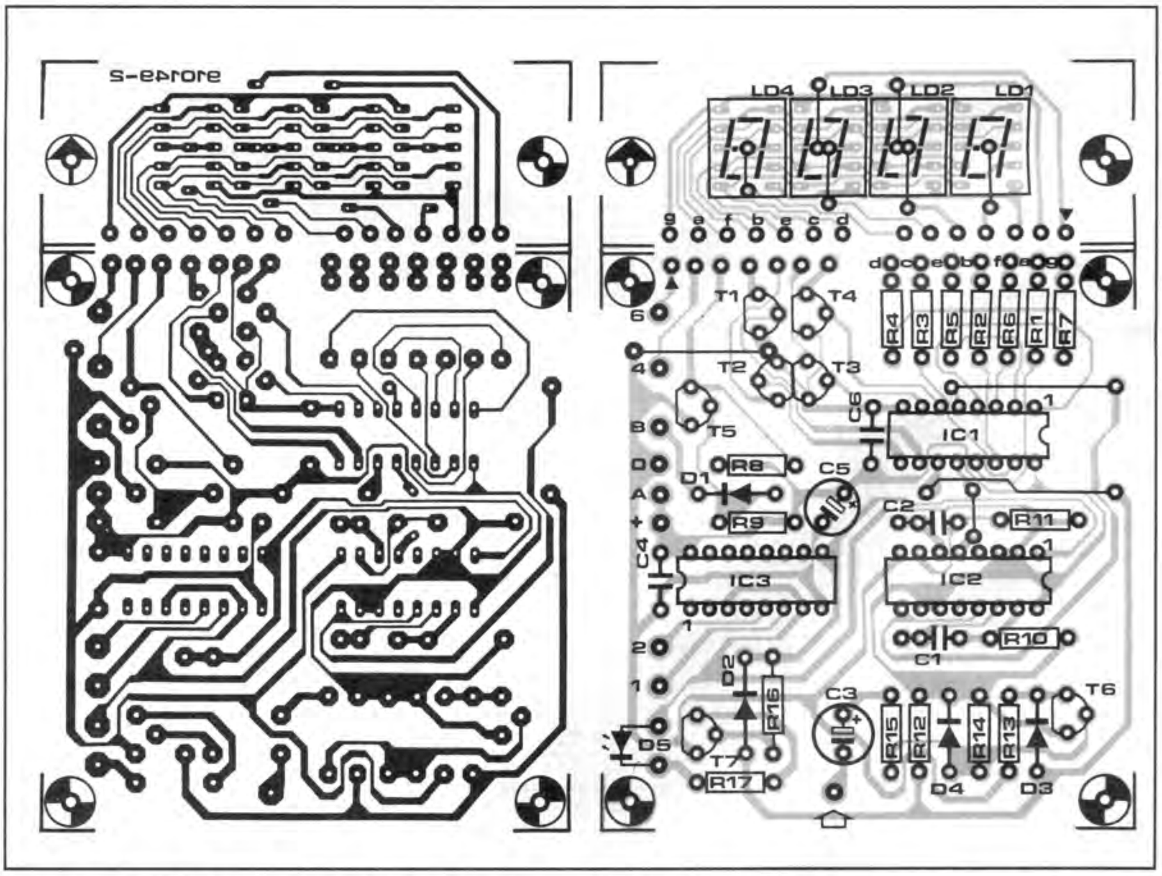


Fig. 6. The printed-circuit board for the counter and the display sections must be cut into two.

Coupling capacitor $C_{10}$ blocks any d.c. component in the input signal; it should, therefore, have a working voltage of ≥250 V.

The signal is applied to amplifier $T_{11}$ via $C_{11}$. The operating point of this stage has been chosen so that not only does $T_{11}$ magnify the signal to a high degree, but, because of its low collector potential, it also acts as a signal limiter. With the value of collector resistor $R_{24}$ as shown, the collector potential with respect to earth is about 0.9 V.

The output of $T_{11}$ is fed via $C_{12}$ to transistors $T_{12}$ and $T_{13}$ that form a Schmitt trigger. When $P_1$ is in a position where the base potential of $T_{12}$ is just insufficient to switch on the transistor, even tiny changes in the base potential suffice to drive $T_{12}$ into conduction. When $P_1$ is set correctly, a sinusoidal input signal of only 10 mV results in a clean rectangular output signal.

A capacitor to couple the preamplifier output to the counter is not required. In fact, when the counter operates with the preamplifier, $C_3$ in its input circuit may be short-circuited or replaced by a wire link.

The power supply for both the counter and the preamplifier needs a transformer rated at 1.5 VA only. Full-wave rectification is provided by diodes $D_{12}$–$D_{15}$. Filtering and regulation by $C_{16}$, $C_{15}$, and $IC_4$, respectively, is standard for this type of supply. Note that the transformer specified is protected against short circuits: the primary circuit, therefore, does not need a fuse.

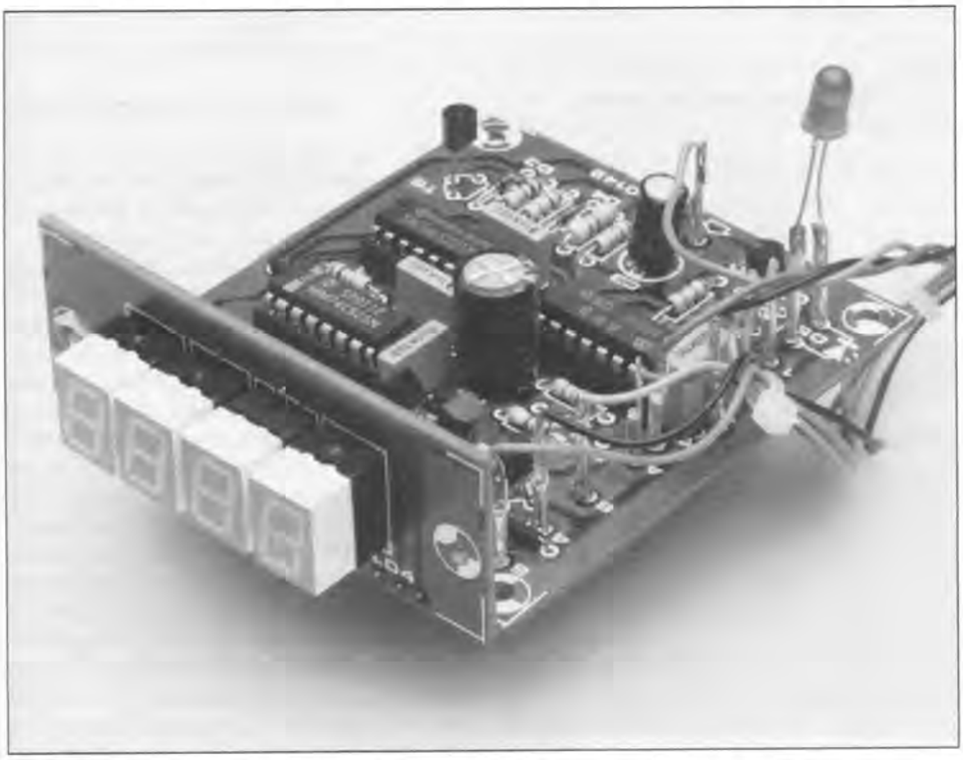


Fig. 7. The display and counter boards must be fitted together at right angles.

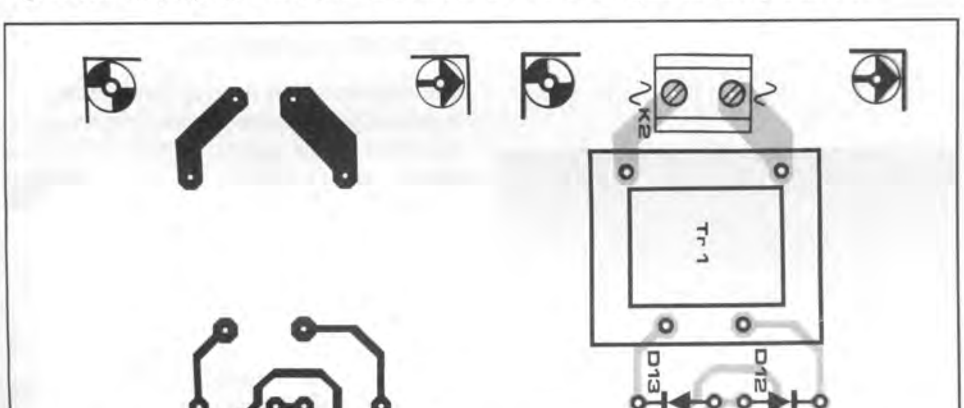


Fig. 8. Printed-circuit board for the preamplifier and power supply.

## Construction

Commence the construction of the counter by cutting off the display section from the board in Fig. 6. After both sections have been completed, they must be soldered together at right angles with the aid of a number of short lengths of bare wire that provide electrical connections between the display board and the counter board at the same time. This construction can be seen clearly in Fig. 7.

No difficulties should be encountered in completing the preamplifier-power supply board.

The modular design enables the counter to be housed in a variety of instrument cases. That of the prototype measured 60×150×132 mm (2 ⅜ × 5 ⅞ × 5 3⁄16 in) (H×W×D). The counter and display boards are fitted to the front panel, while the preamplifier and power supply boards are fixed to the bottom panel. If a metal case is used, the earth plane of the preamplifier-power supply board must be connected to the earth of the input socket only.

Part of the preamplifier, indicated by the dashed line in Fig. 5 and Fig. 8 should be screened from the power supply by a 15 mm high strip of tinplate. It may also prove useful to put a 5 mm screen around these parts at the underside of the board.

The connection between the input socket and $C_{10}$ must be single screened cable.

Voltage regulator $IC_4$ should be fitted on a small heat sink.

## Calibration

Connect an oscilloscope to the output of the Schmitt trigger and inject a 10 mV sinusoidal signal of about 20 kHz into the input socket. Adjust $P_1$ until the waveform on the oscilloscope is a true square wave. If no oscilloscope is available, adjust $P_1$ so that the counter reading remains the same for sinusoidal and rectangular signal inputs (at a level of 10 mV).

The counter has no overflow indication, so that, if, for instance, the 10 kHz range is selected, and the input signal has a frequency of 10.234 kHz, it is displayed as 0.234 kHz. It is, therefore, advisable when an unknown frequency is being measured, to select the highest range first and then go down as required. ■

# SCIENCE & TECHNOLOGY

## Cochlear implants

by Douglas Clarkson

THE array of human sensory apparatus is without question a marvel of adaptive evolution. In particular, Nature has evolved masterful systems for vision and hearing. In both these sensory systems, physical stimuli are translated into nerve impulses, which are in turn processed by the brain. Most of the successes in preserving such sensory systems relate to improving the receptive stages before the nerve stimuli are generated. Thus, restoration of sight can, for example, be achieved by extraction of cataracts. In the improvement of hearing, benefit can come from the use of a hearing aid to amplify the stimulus of the incident pressure waves.

Often, in instances of blindness or deafness, the sensing system has become inoperative, while the nerve pathway to the brain has remained intact. If simulated nerve impulses of appropriate type could be injected into the nerve pathways, some element of sensory perception could, in theory, be retained. While this principle awaits to be developed in visual systems, the use of cochlear implants in hearing research has been successful in providing a means of greatly improving the hearing perception of many thousands of individuals around the world. (The cochlea is the spirally coiled part of the inner ear that translates mechanical vibrations into nerve impulses).

### About the cochlea

A cochlear implant can be described as a specialized hearing aid device that translates patterns of sound into a series of electrical signals which are channelled directly to the auditory nerve for onward transmission to the brain. In so-called single channel systems, the output is attached directly to the auditory nerve. In so-called multi-channel systems, a series of individual electrodes are attached along the interior of the cochlea where, in the normal ear, sound vibrations excite hair cells to generate nerve impulses. This is a more complex surgical procedure but provides better resolution of frequency content of sounds.

The cochlea's highly specialized design causes hair cells within its structure to respond selectively to input signals of various frequencies, so that the pitch of sounds can be finely differentiated. The mechanical properties of the cochlea change from the basal portion (widest) to the apex (narrowest). The stiffness is greatest at the basal end, but its mass per cross section is least, while at the apex the stiffness is least, but its mass per cross section is the greatest. If a range of sounds is coupled into the cochlea at the wide, basal face, specific sections of hair cells within the cochlea will vibrate. Higher frequency sounds will stimulate closer to the wide basal face, while lower frequencies will stimulate areas closer to the apex.

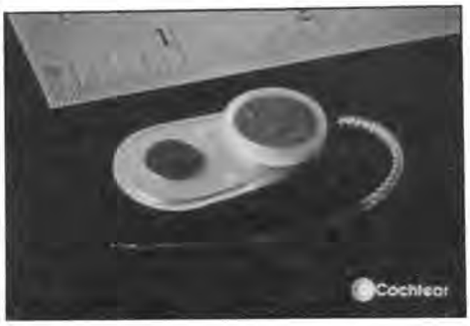


Fig. 1. Cochlear implant unit of the 'Nucleus' system.

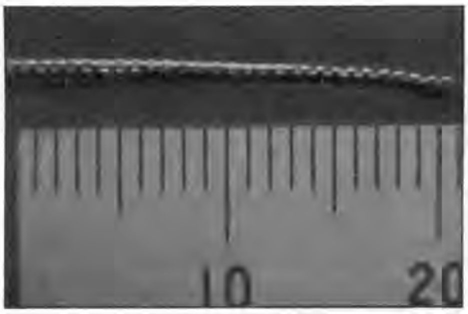


Fig. 2. Close-up on set of electrodes implanted directly in the cochlea.

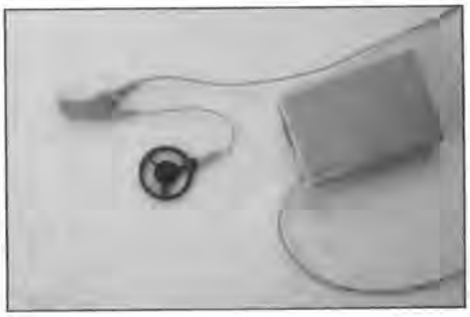


Fig. 3. Speech processor, external microphone and coupler/locator.

In total, there are about 15 000 hair cells along the cochlea, which are connected to about 30 000 nerve fibres in the cochlear nerve. The interconnection pattern can be imagined to be very complex. A particular nerve bundle may be connected to several hair cells or a specific hair cell may be connected to several nerve fibres. The 'design' of the cochlea, however, does allow excellent pitch or frequency discrimination to take place.

Early work on the structure of the cochlea was undertaken by Marchese Alfonso Corti, who first described it in 1851. The theory of the selective resonance of the cochlea was described by Hermann von Helmholtz. A more comprehensive investigation of the cochlea was undertaken by Georg von Békésy, which involved determining the vibrational characteristics of human post-mortem specimens.

### Real time listening

The mechanism of hearing can be imagined to be a real time superposition of electrical signals from all the various sections of the line of hair cells in the cochlea. Any 'artificial' cochlea would have to simulate such a sensing pattern. In particular in terms of frequency response, higher frequency signals require to be injected at the basilar (wide) end and low frequency signals at the apex. This requires an appropriate means of decoding sound into its frequency components and generating appropriate electrical stimuli.

### Design of modern cochlear implants

One type of cochlear implant has a total of 22 electrode sections in order to provide as much pitch discrimination as possible. The degree of such pitch discrimination attained is not sufficiently good, however, to allow normal speech to be understood without the aid of lip reading. Only in very exceptional cases can a cochlear implant provide near-normal hearing discrimination. It must be made clear, however, that the cochlear implant can introduce a totally deaf individual to a world of sounds that puts him or her in touch again with society.

In the design of cochlear implants, there is a major division between analogue and digital systems. Analogue systems tend to have direct connection by wire between the cochlear electrode and the sound analyser/stimulus unit. Digital systems tend to couple stimulation signals using radio frequency linkage. In one sense, the direct coupled analogue system provides the advantage of simplified drive/excitation circuitry, while the digital system minimizes the problem of infection, since the cochlear implant is inserted during sterile procedure and subsequently there is minimum risk of site infection.

## The 'cochlear' system

Figure 1 shows the implanted unit of the 'cochlear' implant developed by the Nucleus Group. Original work on the unit design was undertaken by professor G.B. Clark and his colleagues at the University of Melbourne, Australia, during the early 1970s. The implanted unit consists of a magnet to localize the external radio linkage system and microelectronics to pick up power and signals in order to drive the array of 22 electrodes.

Figure 2 shows the array of electrodes that is inserted into the cochlea. The 22 electrodes are bands of pure platinum 0.3 mm wide and spaced at 0.75 mm intervals along a silicone elastomer carrier. The array tapers smoothly from a diameter of 0.6 mm at its widest part to about 0.4 mm at the tip.

In the driving of the individual electrodes, current can be driven between specific pairs of electrodes or between a specific electrode and all the remainder acting as a common ground. It can be appreciated that some degree of customizing of each system is required to optimize performance. This is typically undertaken by testing hearing responses with a so-called implant centre system, where current driving patterns can be tailored on a master system before being incorporated in the patient's own device. Specific performance of, for example, consonant recognition can be evaluated for a range of electrode driving configurations.

Figure 3 shows the microphone, external sound processor and magnetic locator/stimulator unit. The external sound processor is usually worn on a carrying pouch.

## Speech processing mechanisms

Speech elements can be identified as those involving vocal chords such as 'eeee' or 'ah' and those which do not, such as 's', 't' and 'k'. These are the so-called 'voiced' and 'unvoiced' sounds. If the speech processor firstly identifies that 'voiced' sounds are present, it then determines the peaks in the frequency analysis of the sound and their relative signal amplitude. Subsequently, it identifies from look-up tables what is the appropriate electrode pattern to stimulate. The required information is coupled via a 2.5 MHz RF link to the implant electronics in order to drive the electrode configuration.

For unvoiced speech elements, the speech processor stimulates electrodes towards the basal, high frequency end of the cochlea. The speech processor is, therefore, implementing a first level of speech recognition for voiced sounds.

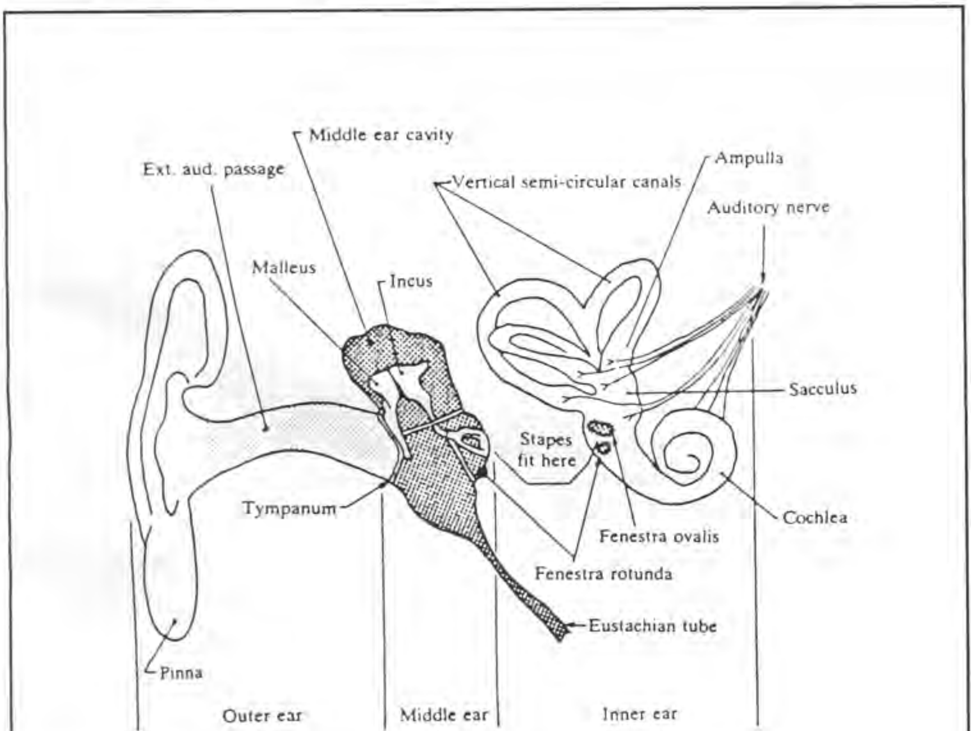


**Fig. 4. The ear consists of three sections: the external, the middle and the inner ear. The external ear extends from the external ear lobe (pinna) to the ear drum (tympanum). The middle ear acts as an amplifier with a gain of about 25 dB. The inner ear consists primarily of the fluid-filled cochlea. Electron microscopy has shown that exposure to high levels of noise results in irreparable damage to the hair cells mounted on the basilar membrane, which then appear to be 'bent over' and no longer capable of generating a nerve signal for the brain to interpret.**

Developments in performance of such speech processors are primarily being derived from increasing the processing speed of the microprocessor circuit elements. This allows for both faster decoding of speech patterns and more complex algorithms to be implemented. In the longer term, it is possible that systems will include more general word recognition features, though this is not a feature of current systems.

## Driving patterns of current

It is known that direct current flowing in sensory nerve channels can result in damage to sensitivities. The stimulus waveforms in the Nucleus system are biphasic or charge balanced so that the averaged current flow across the electrodes is close to zero (< 1 µA).

The typical duration of a phase is 200 µs with pulse amplitudes of 100–800 µA. It is appreciated that there is a danger in overdriving neural circuits that are connected to the main central nervous system. Current driving amplitudes that can be readily tolerated in most patients can result in facial pain or facial muscle spasm in a small number of cases.

## Uptake of cochlear implant technology

To date, there have been over 5 000 cochlear implants undertaken world-wide using a variety of designs. The group of patients who typically receive such treatment are those with total loss of hearing in both ears and where conventional devices such as hearing aids and inner ear surgery can provide no benefit. It is vital, of course, that the appropriate auditory nerve is still functional.

Owing to the nature of both the technology of the implant system and the range of professional skills required in the 'implant' team, such treatments are relatively expensive. However, in assessing costs and benefits, individuals can usually achieve a higher level of participation in society. In recent years, children have become a major group to receive such implants. This is natural, since their development is critically dependent on communicating effectively with those around them.

In the United Kingdom, a set of seven centres has been established where cochlear implants can be undertaken. There has been disappointment, however, at the limited resources provided to undertake such a programme. The demand for such services far outstrips present levels of funding.

## 'Looking' ahead

On a more distant horizon, probably in the mid to late 1990s, artificial retinas may well be introduced in their prototype forms. The groundwork with artificial cochleas will, no doubt, serve as useful experience in this much more challenging development. ■

# A DIRECT CONVERSION RADIO

**Amateur radio is expensive, or should I say it is if you buy all of your equipment. This cost deters many from a hobby that once investigated niches where low cost home built equipment can be used to the full. Equally, others may have become tired of just using a purchased rig and the chance to build and use a simple radio may put life back into the hobby.**

**by David J. Silvester G4TJG**

THE author wanted to build a low cost transceiver as an experiment to see just what can be achieved. For simplicity, this means the radio is built for a single band and that many of the complications that make a communications transceiver so costly can be dispensed with. As to the frequency, it was decided that the 14-MHz (20-m) band would be best. I prefer that band to the more familiar option of 3.5 MHz (80-m), because I could get a reasonable dipole antenna into my back garden because of its smaller size.

It was felt that owing to the experimental nature of a transceiver I set out to design that it would be a reasonable idea to construct the receiver section as a separate project to iron out any technical problems, and to see what sort of signals could be heard from such a low cost unit. The most successful of the designs forms the basis of this article.

## Direct conversion, how it works

Communication receivers tend to use the double conversion superheterodyne techniques. By contrast, the much simpler direct conversion technique is based on one stable oscillator which actually runs at the same frequency as the signal being received and all of the filtering is carried out at AF where an inductor-capacitor bandpass filter is easy to design and build. Direct conversion receivers are for use with single sideband and CW transmissions, but with care the receiver will demodulate AM signals, although the carrier causes a problem as detuning leaves a loud whistle in the headphones, and the receiver will need to be set accurately to null this out.

To examine direct conversion, consider an incoming upper sideband signal that would have had a 14.200-MHz carrier if this were not removed prior to transmission. In the direct conversion receiver, the band of signal frequencies that have been transmitted is mixed with a stable signal of 14.200 MHz generated within the receiver. In the mixer, the sum and difference frequencies are generated and the difference, which is an audio signal, is filtered out from the remaining frequencies which are all RF. If the internal oscillator is only slightly away from the correct frequency, the signal will still be resolved, but the audio tone will be higher or lower depending on the difference. However, if the receiver's oscillator is set, say, 3 kHz above the correct missing carrier frequency of an upper sideband signal, the signal is treated as lower sideband and a characteristic direct conversion tuning sound results.

## Circuit description

### The mixer

The mixer is the heart of the direct conversion receiver, and whilst any type can be used for the receiver, it was felt that one of the balanced mixers available as a complete package would be the most suitable to use when the transceiver option was considered. By using one of these balanced mixers, the oscillator can be left running all of the time into one of the mixer's input ports, so that this tends to stabilize its frequency. Also, local oscillator radiation is a serious problem in direct conversion receivers and the balanced nature of the mixer chosen assists in preventing unwanted signal leakage. Unlike the situation in the superhet receiver, the antenna and input bandpass filter are tuned to the local oscillator frequency and any leakage will be transmitted. An isolator stage can be added to try to prevent this and good screening needs to be placed between the

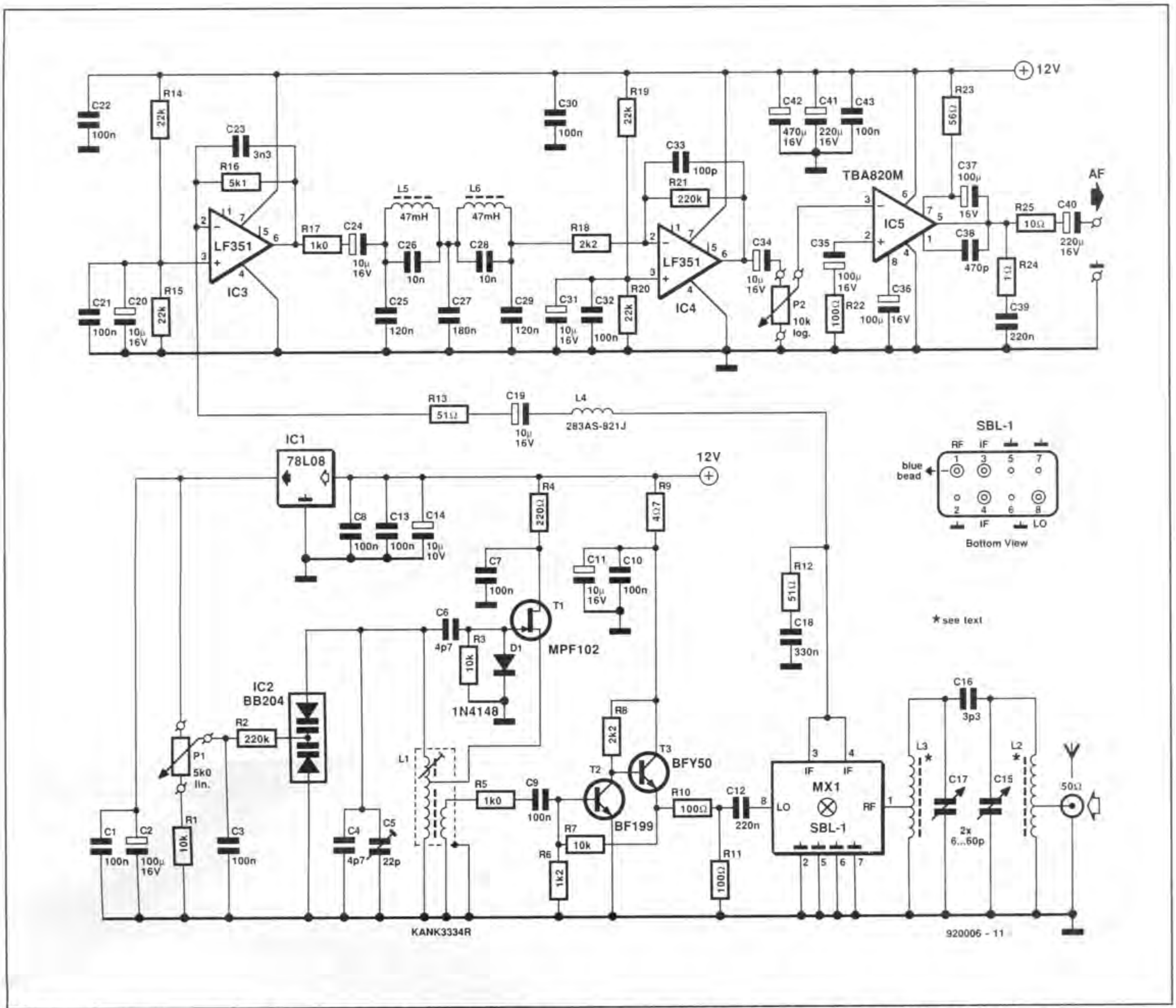


**Fig. 1. Circuit diagram of the direct conversion receiver. This version is designed to work on the 20m amateur radio band.**

local oscillator and RF circuits.

### The oscillator

Essential for the design is the stability of the single oscillator that in this case runs from 13.950 MHz to 14.400 MHz. This oscillator must be stable to within a few hertz after a short warm-up period, or the user will forever be retuning the radio. Also, the oscillator needs to be resettable so that the oscillator control can be calibrated, and a conversion chart drawn up. In fact, the tuning capacitance has to change by only a very small amount to obtain the tuning range we need, and it was decided that the simplest option was to use a variable capacitance diode pair as the frequency controlling element in the design. Here, the varicap control is carried out by voltage derived from a 10-turn potentiometer.

Figure 1 shows the full circuit diagram for the radio. The oscillator is a well-proven type using a FET as the active device. Diode D1 and resistor R3 provide gate bias for FET T1. The tuned circuit consists of the inductance of L1 and the parallel capacitance of C5 and the varicap diode pair, IC2. C4 was not needed for the 20-m band but since the receiver can be made to tune to other frequency bands it is included for completeness. Feedback to maintain oscillation is taken from a tap on the primary winding of the inductor, and the output from the oscillator is from a small secondary winding (tank) so that the following buffer only lightly loads the oscillator.

During development an MPF102, a BF245 and a 2SK55 were tried in the position T1. In all cases the output was identical, so any of these and possibly many other FETs may be used, although some care will need to be taken to assure that the FET leads are connected correctly as the pinouts do vary between types.

If a single varicap diode is used, a problem occurs because its capacitance changes as the oscillator operates (since its bias then varies). To overcome this, the oscillator uses a back-to-back common cathode varicap pair in a single TO92 package, in which as one diode loses bias, the other receives extra bias and the capacitance across the anodes remains approximately stable. This raises another problem in that both diodes must be held in reverse bias even though the anode voltage at the upper end connected to the winding will be varying at the 14-MHz frequency. This is overcome by making the minimum central bias voltage higher than the peak RF voltage at the top end of the coil. The bias voltage is derived from the portion of the output voltage of the 8-V regulator, IC1, that is selected by the potential divider consisting of the 10-turn potentiometer P1 and resistor R1. This voltage can never be less than 5.3 V and allows a 6-V peak RF voltage at the top of the tuned circuit. A 10-turn pot, although costly, was chosen because an indicating dial can be used with this type of pot and the dial reading can be directly related to the receiver frequency.

Capacitors C1, C2 and C3 provide stability for the tuning voltage and prevent the oscillator signal feeding back into voltage regulator IC1. During operation, no current flows out of the varicap except for leakage currents, so resistor R2 provides an RF block whilst passing the DC voltage needed to bias

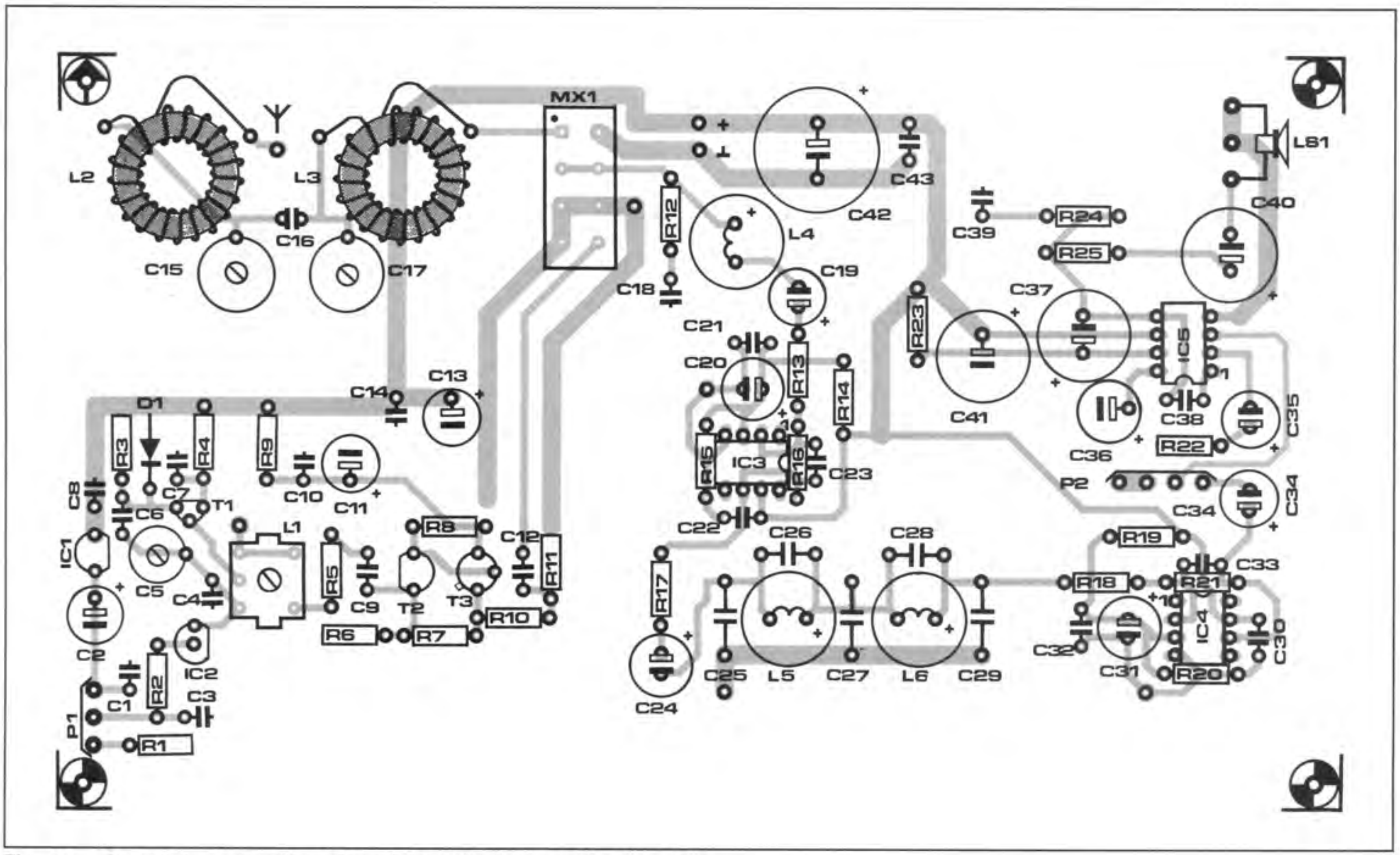


**Fig. 2a. Component mounting plan of the PCB designed for the radio.**

the varicap. R4 and C7 isolate the FET's drain from the power supply at 12 V, as feedback of RF may affect the other RF circuits.

The second stage, the circuit around T2 and T3, is a buffer amplifier to raise the signal available at the transformer tap to about 1.5 $V_{pp}$ into a 50-Ω load to drive the balanced mixer correctly.

### The RF circuit and mixer

The input circuit is extremely simple. Two identical tuned circuits with a top connecting capacitor act as a bandpass filter for the incoming signal. They have a *Q* of 10 with the 50-Ω impedance presented by the antenna and the mixer's input. The top loading capacitor, C16, couples the signal between them. The SBL-1 mixer has a single-ended 50-Ω input at pin 1, a 50-Ω local oscillator input at pin 8, and the output is available at pins 3 and 4. The output consists of the sum and difference frequencies as well as any signal that leaks through the mixer. Of these, the difference is the audio signal we select and amplify—all the others are RF signals.

### AF filter and amplifiers

Initial RF rejection is provided by R12-C18 with L4, C19 and the 50-Ω input impedance of the first opamp stage. This presents a constant impedance of 50 Ω to the mixer. At AF, the signal passes to the 50-Ω amplifier input impedance through L4, whilst at RF R12 and C18 maintain the 50-Ω impedance.

The main audio filter consists of L5, L6 and C25 to C29. This is a low-pass filter with a high cut-off rate above 3 kHz to attenuate signals outside the normal SSB range. This does lead to the possibility of receiving more

## COMPONENTS LIST

**Resistors:**
(all 250mW 5% carbon or metal film)

| | | |
|---|---|---|
| 3 | 10kΩ | R1;R3;R7 |
| 2 | 220kΩ | R2;R21 |
| 1 | 220Ω | R4 |
| 2 | 1kΩ | R5;R17 |
| 1 | 1kΩ2 | R6 |
| 2 | 2kΩ2 | R8;R18 |
| 1 | 4Ω7 | R9 |
| 3 | 100Ω | R10;R11;R22 |
| 2 | 51Ω | R12;R13 |
| 4 | 22kΩ | R14;R15;R19;R20 |
| 1 | 5kΩ1 | R16 |
| 1 | 56Ω | R23 |
| 1 | 1Ω | R24 |
| 1 | 10Ω | R25 |
| 1 | 4kΩ7 lin. 10-turn | P1 |
| 1 | 10kΩ log. | P2 |

**Capacitors:**
(all 16V or greater voltage rating)

| | | |
|---|---|---|
| 12 | 100nF ceramic | C1;C3;C7;C8;C9;C10;C14;C21;C22;C30;C32;C42 |
| 8 | 10µF radial | C2;C11;C13;C19;C20;C24;C31;C34 |

C4 space made for optional frequency use; not needed for 20-m receiver

| | | |
|---|---|---|
| 1 | 22pF trimmer | C5 |
| 1 | 4pF7 ceramic | C6 |
| 2 | 220nF ceramic | C12;C39 |
| 2 | 60pF trimmer | C15;C17 |
| 1 | 3pF3 ceramic | C16 |
| 1 | 330nF ceramic | C18 |
| 1 | 3nF3 polyester | C23 |
| 2 | 120nF polyester | C25;C29 |
| 2 | 10nF polyester | C26;C28 |
| 1 | 180nF polyester | C27 |
| 1 | 100pF ceramic | C33 |
| 3 | 100µF radial | C35;C36;C37 |
| 1 | 470pF ceramic | C38 |
| 1 | 220µF radial | C40 |
| 1 | 470µF radial | C41 |

**Semiconductors:**

| | | |
|---|---|---|
| 1 | 78L08 | IC1 |
| 1 | BB204 | IC2 |
| 2 | LF351 or TL071 | IC3;IC4 |
| 1 | TBA820M | IC5 |
| 1 | MPF102 | T1 |
| 1 | BF199 | T2 |
| 1 | BFY50/51/52; 2N3053 | T3 |
| 1 | 1N4148 | D1 |

**Inductors:**

| | | |
|---|---|---|
| 1 | Toko KANK3334R | L1 |
| 2 | T68-2 core (Micrometals). | L2;L3 |
| 1 | Toko 283AS-821J | L4 |
| 2 | Toko 181LY473 | L5;L6 |

**Miscellaneous:**

| | | |
|---|---|---|
| 1 | SBL-1 | Mx1 |
| 1 | 10-turn indicator. | |
| 1 | Knob for AF volume control. | |
| 1 | Diecast aluminium box 190×110×60mm. | |
| 1 | RF input socket BNC or SO239. | |
| 1 | Walkman type headphones | |
| 1 | Power input socket | |

Short lengths of UR43 RF coax for balun connection, some audio coax for the headphones adapter, hookup wire, stand-offs, 26SWG (0.45-mm) enamelled copper wire.

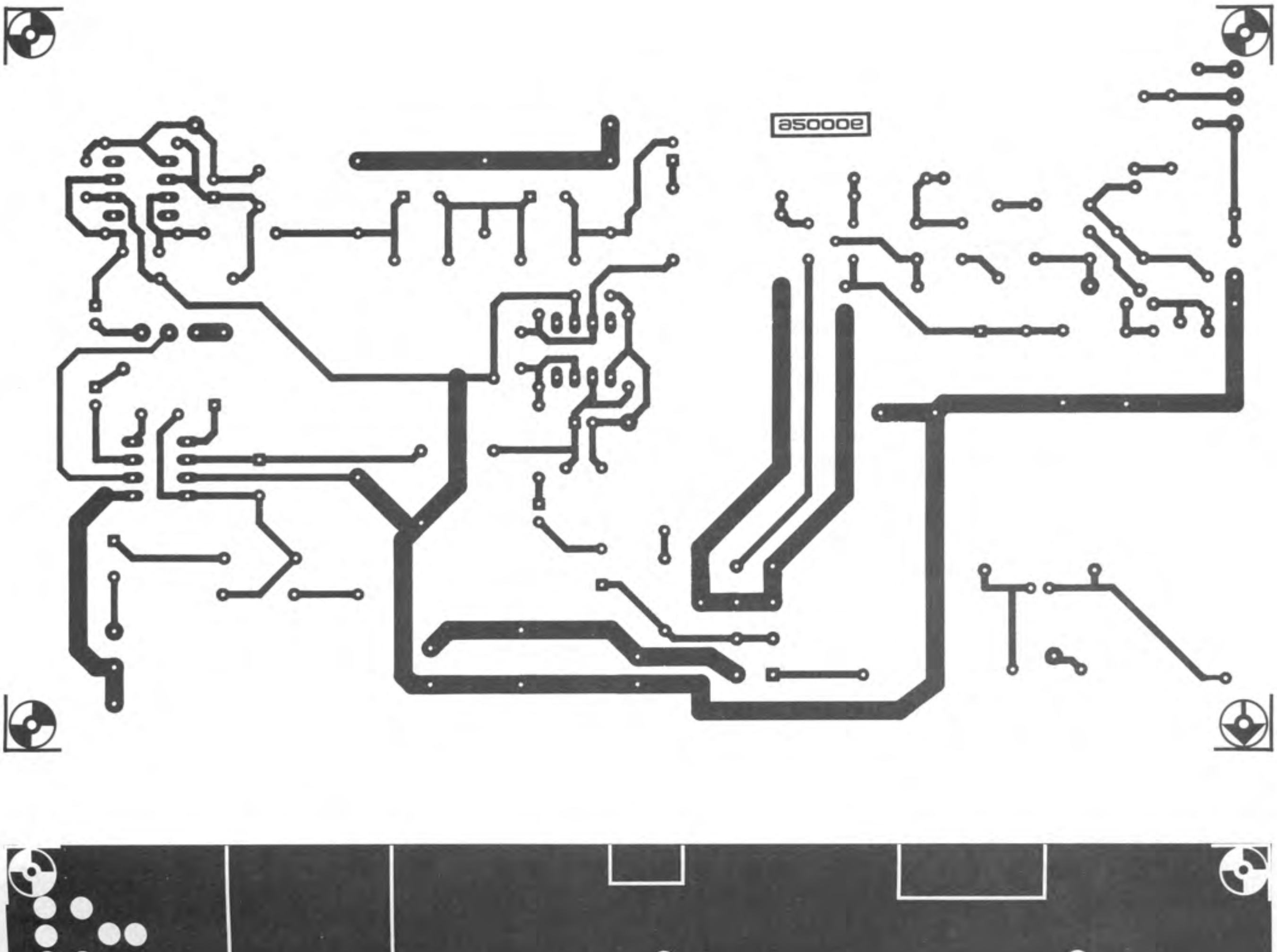


Fig. 2b. Track side and component side copper layout. The component side need not be etched as shown here; see the text for details.

than one CW signal if they are closely spaced, but it was felt that most users would be listening to SSB transmissions. If required, a narrow band select filter at AF could be added for CW listening.

The AF amplifier has three stages: two simple inverting opamps biased for use with a single power supply, and a dedicated low power amplifier. The first stage around IC3 has an input impedance of 50 Ω defined by R13, and a voltage gain of 100 (equivalent to 40 dB) set by feedback resistor R16. R16 is also shunted with a capacitor, C23, to cut down on the high frequency gain of the amplifier, the cut-off being set at about 10 kHz.

As the receiver has a single power supply of 12 V only, the non-inverting input to the opamp has to be held at about 6 V to put the opamp into its linear operating region. This voltage is provided by R14 and R15 with C20 and C21 to remove any a.c. from the opamp input. Capacitor C24 removes the d.c. off-set at the output of IC3, passes the AF signal to the main filter, and provides low frequency attenuation of the AF signal. The second opamp stage around IC4 provides another 40 dB of gain before the signal is passed to the volume control, P2, and on to the power amplifier, IC5.

The AF power amplifier has a gain of about 35 dB, so the whole receiver has a voltage gain of about 75 dB, which is lower than normal but allows for an RF buffer amplifier, and in fact seems adequate for the job anyway.

The output audio is to stereo headphones with the two earpieces connected in parallel. An adaptor was built to do this, and to allow two sets of headphones to be used at once. C40 isolates the d.c. on the output of the power amplifier IC from the headphones.

To ensure stability, the two ICs in the AF amplifier have capacitors across their supply pins.

## Construction

The whole circuit, except for the two potentiometers, is mounted on a single PCB, shown in Fig. 2. This board has its lower surface etched to form the track pattern and the upper surface either left unetched as a solid ground plane, or etched as shown.

In the first case, the lower surface of the board will be exposed, developed and etched as usual, but the upper surface will need to be kept covered to prevent any removal of the copper layer. In the final stage of board production, holes are drilled through all of the pads on the lower surface. A 1-mm drill seems to be the best size for this operation. There are eight through board connections where the upper ground plane must be left close to the holes. Where the component wires must pass through the PCB without shorting to ground, a 2-mm ring of the copper is removed from around the holes on the upper surface. The author uses a ⅛-inch (3-mm) drill mounted in a handle for this. In many cases, the components have one terminal bent and soldered to the upper surface of the board.

If the component side of the board is etched as shown, it is not necessary to clear the holes where component wires pass through to the track side. However, grounded component wires must also be bent and soldered flush on to the ground plane.

**Parts for Balun:**

Potting box 23mm; cubical type.
Potting compound: 50g will do two baluns with a little over.
Coax connector BNC type.
Spade terminals.
Ferrite core Micrometals T72-26.
26SWG enamelled copper wire.

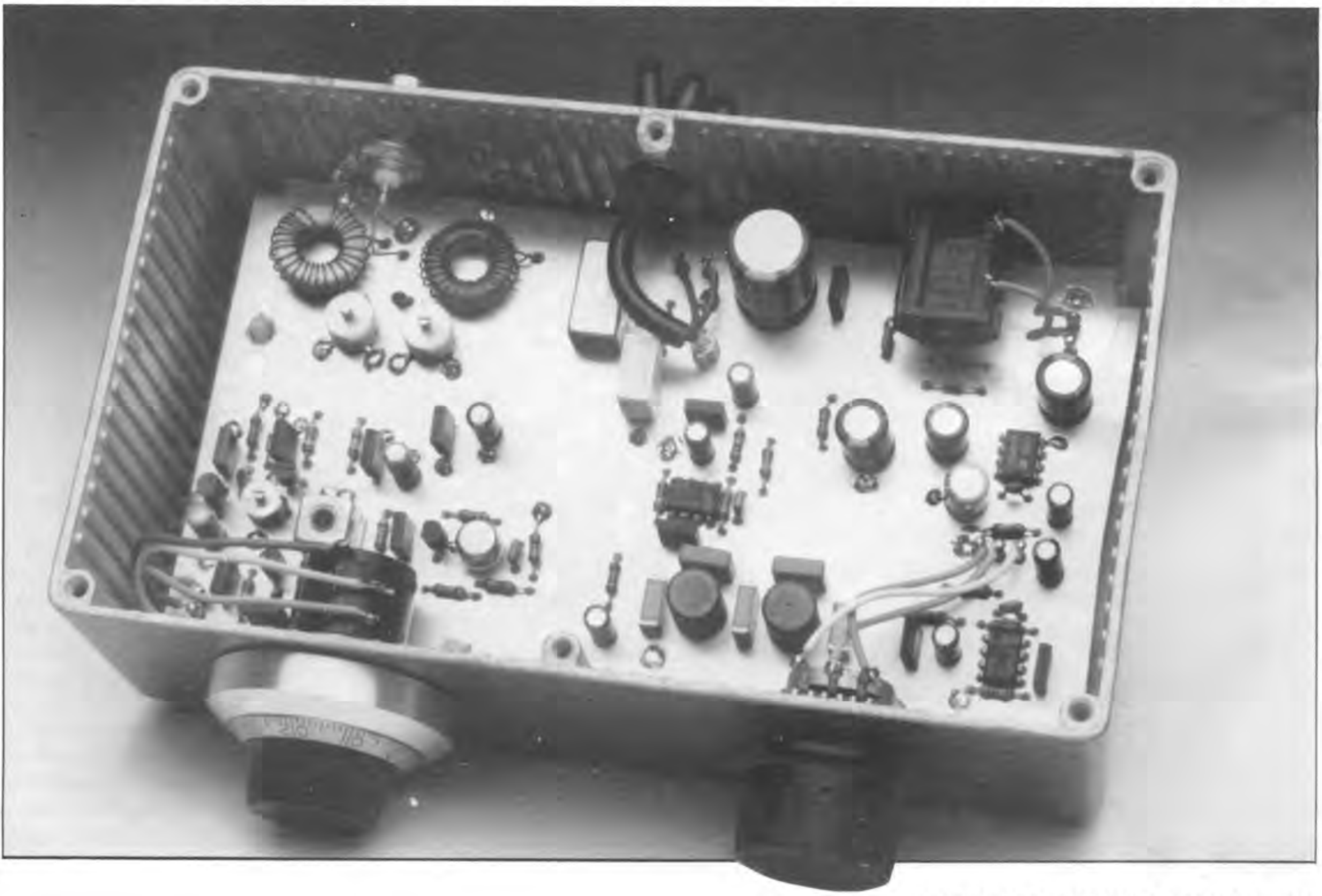
**Parts Sources**

Cirkit Distribution Ltd. at Broxbourne supply all of the Toko coils and the Micrometals cores as well as many of the other items. Maplin Electronics supply the potting boxes and

The can tabs of inductor L1 are also connected to the ground plane by bending them out to the side and soldering to the upper surface. The ground plane is a good conductor of heat as well as electricity, and a fairly large soldering iron bit needs to be used if joints to the ground plane are to be successful. If a large soldering iron is used to solder the small pads on the lower surface, great care must be taken to avoid damaging them, or damaging the components by overheating.

To fit into the recommended box, the corners of the PCB and a section at the centre will need to be removed to allow the PCB to pass the screw mountings. These should be cut out at an early stage of PCB construction.

Construction is best carried out in the fol-



lowing order. Firstly, locate the position for the inductor and the two ICs, as they are easy to find due to the distinctive pin layouts. Fold back the tabs on the inductor cans and tin them. Insert the inductor, solder the pins, and solder the tabs to the ground plane. Locate the position for the eight through-board connections, push track pins or short pieces of wire through to make the connections, and solder to both the upper ground plane and the lower track.

Care needs to be exercised when building the PCB as the components are tightly packed in some areas. Construction should cause no problems but the usual care should be taken especially over the connections to the ground plane, as there is no indication of the orientation for these components from the holes alone. It is easier to build outward from the centre, but make sure that the resistors and capacitors associated with an active component are in place before fitting the semiconductor itself.

In the prototype, the three ICs were soldered into the board instead of fitted into sockets, as board mounting is advantageous with inexpensive ICs like these.

The only components not on the board are the two potentiometers. The 10-turn pot, P1, carries d.c. signals only, and the RF pickup that may occur is shorted to ground on the board itself. The second pot, P2, carries AF signals at fairly high amplitude. Hence both pots are connected to the PCB by single strand hookup wire.

The antenna connection is made through two toroidal inductors that have to be wound by hand. Take a 2-ft (approx. 60-cm) long piece of 26SWG (0.45-mm dia.) enamelled copper wire, scratch away the insulation about 6 inches (15 cm) from one end, bend in the middle of the bared section and twist together for about 1 inch (2.5 cm). This will form the tap connection. Place the wire against one of the toroidal cores and wind the short end of the wire through the core for 5 turns. This tail forms the ground connection. Next, wind the longer wire in the opposite direction for 20 turns. This is the connection to the two tuning capacitors and the link capacitor. Repeat with a second core and piece of wire. You will now have two 25-turn coils with taps at 5 turns suitable for use with a 50-Ω antenna and the 50-Ω input to the mixer. Should you find that you would like to use a 75-Ω antenna impedance (see the section on antennas later) then the antenna toroidal winding needs to have the tap at 6 turns instead of 5. Solder the input coils onto the board. Then solder in wires for the off board connections.

The choice of audio socket will depend on the plug fitted to the headphones. Rather than replace this plug, a mating socket of the correct size can be used, or an adapter made, but the two terminals that carry the different signals in stereo operation need to be connected together at the socket. The authors radio has a standard jack socket in the box and an adapter to two paralleled 3.5-mm stereo headphone sockets so that two can listen in comfort. The 12-V power input may be either by way of wires and a grommet or by one of the power plugs, depending on the constructor's preference.

Two types of dial for the 10-turn pot are suitable: round dial types have large control knobs which ease the tuning but are more complicated to read.

The board is a close fit into the box to allow the ground plane to sandwich the tracks between it and the box. This serves to keep down spurious radiation. Locate suitable positions for the pots and input sockets for the antenna, the 12-V power supply, and the headphone socket, preferably very close to the connection points on the PCB. Use PCB stand-offs to hold the board away from the box. Drill holes for these in the board, but try to ensure that they do not interfere with the pots or connections. The radio is used with the box inverted, so that there were no ugly holes in the top of the box. The stand-offs were stuck into the box rather than screwed down. Drill the holes in the box for the pots and connectors and fit any lugs that are necessary to locate the 10 turn pot indicator. Next, fit the pots and connectors and carry out the final wiring.

The pots are connected so that a clockwise rotation of the knob increases frequency or audio output. The clockwise end of P1 connects to the pad going to C1 and C2. The clockwise end of P2 is connected to the pad to C34, otherwise the controls will not work in the expected manner, and the rig will be difficult to use.

## Aligning the rig

The ease of setting up the rig depends on the amount of equipment available. The receiver is designed to work from a 12-V power pack normally intended for powering CB equipment with an actual output voltage of around 13.6 V. Although the aluminium box used to house the receiver is a good electrical screen, it does not give any magnetic shielding. Unfortunately, the magnetic field of the mains transformer in the power supply can couple to the inductors L4, L5 and L6, giving a very distorted audio output. The separation only needs to be about a foot (30 cm) or so to stop the pickup.

All three of the variable capacitors C5, C15 and C17 are initially set to a central position, and the tuning control, P1, is set so that the voltage at the end of R2 is 8 V. This should be at the fully clockwise position if the pot has been installed correctly, and equates to an oscillator frequency of 14.4 MHz.

If an oscilloscope is available, connect this to the emitter of T3. Next, adjust the core of L1 until the peak to peak voltage at the emitter is 3 V or greater. Ignore frequency at this stage. Alternatively, a digital voltmeter with an RF probe accessory can be used, and the reading set to 3 V as before.

A digital frequency meter is helpful in setting the frequency range of the oscillator and thus calibrating the receiver, but this can be carried out using another receiver or by using a calibration signal from a crystal oscillator. Check that the oscillator can be set to cover the range 14.0 MHz to 14.4 MHz which covers the 20-m amateur band, and calibrate the read-out with the dial on the ten turn pot.

If no scope or DVM is available, the core of L1 can be set to the correct frequency with C5 left in the central position. The oscillator output will be sufficiently close for most users.

Once the oscillator is set, the rest of tuning amounts to adjusting the other variable capacitors for the maximum audio output from a weak input to the antenna socket. This may be an off air signal or from a signal generator or grid dip oscillator.

True alignment and calibration needs a digital frequency meter, a crystal calibrator or the loan of a communications receiver. If you are a member of a radio club, this equipment will probably be available, and members may be willing to help for the few minutes that calibration takes.

## Setting up the antenna

Anyone new to radio listening will need to set up an outdoor antenna of some type if any reasonable reception is to be achieved. Fortunately, this does not need to be elaborate, although a dipole antenna works much better than a long wire. The author's favourite is made from 300-Ω ribbon cable. Take a piece of ribbon cable 28 ft long (approx. 8.4 m) and join the two conductors at both ends. Fold the antenna to find the centre, and cut one of the conductors at the centre. Take another length of 300-Ω ribbon cable to form the feeder, this can be of any length; because it is thin and flexible it can be brought into the house through a window. Suspend the antenna in the open air and lead the feeder into the house. Cut this ribbon cable off a short distance inside the house.

The radio is designed for a 50-Ω or 75-Ω single-ended (unbalanced) input, but up to now our antenna is of a balanced type. To convert the 300-Ω balanced to 75-Ω single ended we need to make a balun. In practice, the balun is wound on a ferrite core. Take two pieces of 26SWG (0.45-mm dia.) enamelled copper wire about 2 ft (60 cm) long, twist them lightly together, and wind as a pair for 15 times through the core. Cut the ends off to about 3 to 4 inches (7.5 to 10 cm) and scrape away the insulation on all of the wires. Use an ohmmeter to find the start of one wire and the end of the other, and twist them together to give the central tap. Wire the ribbon cable antenna feeder across the full winding, and a 75-Ω coax with the core to one of the ribbon wires and the screen to the central tap. The other end of the coax connects to the radio through a plug and socket on the aluminium case. In this form, the balun is rather rough and ready although fully operational. If you want the thing to look nicer, the balun can be potted in a small box made for that purpose and having a coax connector at one end and two spade terminals for the ribbon cable connections. ■

# DESIGN IDEAS

The contents of this column are based solely on information supplied by the author and do not imply practical experience by *Elektor Electronics*

# Exploring negative resistance: the lambda diode

**by Samuel Dick**

RESISTANCE is omnipresent in electronics. A few materials (super conductors) lose their resistance at fairly low temperatures, and all materials lose it completely at absolute zero. However, at normal temperatures, most (conducting) materials obey Ohm's law, but some show characteristics of negative resistance. Are these breaking Ohm's law? And what good is negative resistance?

## Dynamics

Ohm's law must be one of the simplest (and most remembered?) equations of elementary electricity. To determine the resistance of a component, apply a voltage across it and measure how much current flows through it. The resistance equals the voltage divided by the current:

$R=U/I$,

where $R$ is in ohms, $U$ in volts and $I$ in amperes.

For many objects, their resistance may be thought of as constant. If a resistance is plotted over a wide range of voltages as in Fig. 1, it will be seen to be pretty linear: the resistance is the reciprocal of the gradient. But this situation is true only under certain conditions. If the temperature at which the measurements are made is varied, (slightly) different values of resistance will be obtained. For instance, the value of most carbon film resistors changes by 0.03% °C$^{-1}$. However, for most purposes, the humble carbon resistor is regarded as being 'linear': the current through it is directly proportional to the voltage applied across it.

Not all devices are so well behaved and we need not look at exotic devices to find an example. The wire-filament light bulb is non-linear! As the voltage applied across it is increased, the filament heats up and its resistance increases. The bulb will pass a lower current at higher voltagessee Fig. 2. A similar effect is seen with a diode: it passes little current as long as the applied voltage is below 700 mV (at least, in case of a silicon diode).

A device may, therefore, have different values of resistance, depending on the level of voltage applied across it. The application of Ohm's law is always correct, because its answer is the resistance at the instant the measurement was made, that is, with constant circuit parameters. When the resistance of the light bulb or diode was measured, the voltage was kept constant when the current was measured. Because the resistance was measured in this way, it is referred to as static resistance.

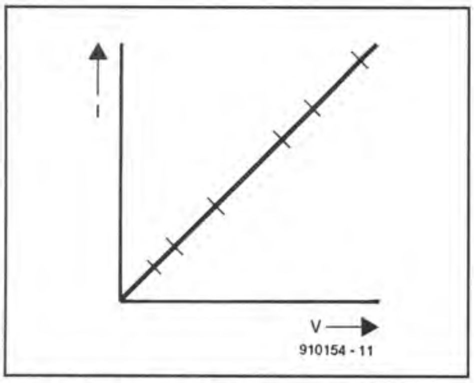


**Fig.1. *V–I* curve of simple resistor.**

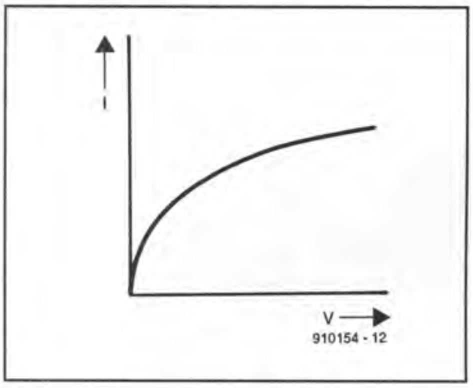


**Fig. 2. *V–I* curve of electric light bulb.**

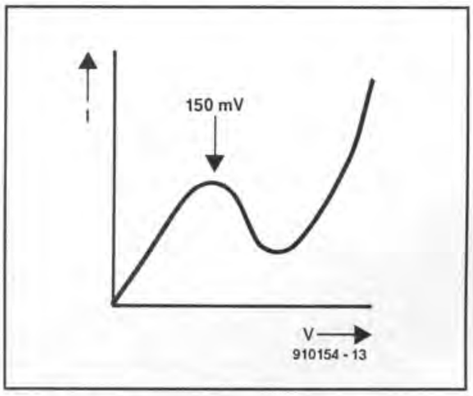


**Fig. 3. *V–I* curve of tunnel diode.**

A more interesting notion is that of dynamic resistance. If Figures 1 and 2 were plotted with the current rather than the voltage along the $x$–axis, the resistance at any point would be merely the gradient of the curve. This is referred to as the dynamic resistance because it is measured as a resultant of changing circuit parameters.

While the static resistance is the voltage divided by the current, the dynamic resistance is defined as a change in voltage divided by the (resultant) change in current. In this definition, it should also be noted at what voltage the dynamic resistance was measured. In the case of a resistor, the dynamic resistance is constant and equal to the static resistance. But for the light bulb or the diode, the gradient, that is, the dynamic resistance, of their curves is a function of the applied voltage.

If the gradient of most devices is plotted, it will be found to be invariably positive. But for a few devices, part of the curve has a negative gradient, and thus a negative dynamic resistance. For instance, Fig. 3 shows the behaviour of a tunnel diode: at a voltage of 150 mV, the current stops increasing and decreases instead. The tunnel diode, in this region, has negative resistance. Of course, if you applied a voltage of, say, 200 mV (in the negative slope region) and measured the current, it would have a sensible, positive value. It is not the static resistance that is negative, but the change in current is in the opposite sense (it decreases) compared with normal positive resistance devices when the voltage is increased.

But how is negative resistance used? Tunnel diodes are used in oscillators, monostable and

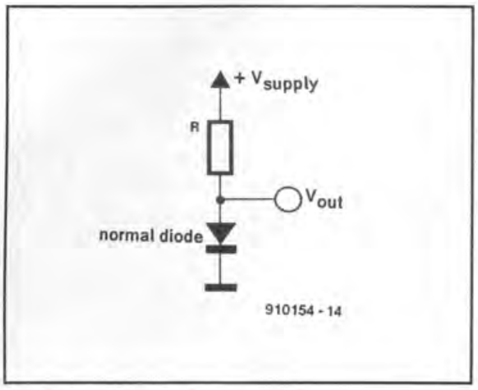


**Fig. 4. Series resistor-diode network.**

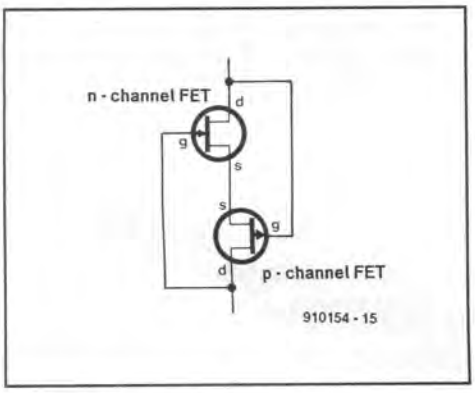


Fig. 5. The lambda diode.

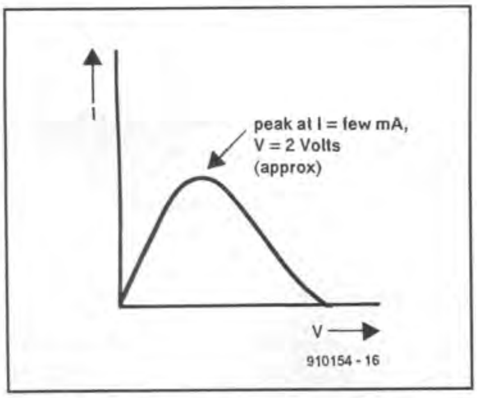


Fig. 6. *V–I* curve of the lambda diode.

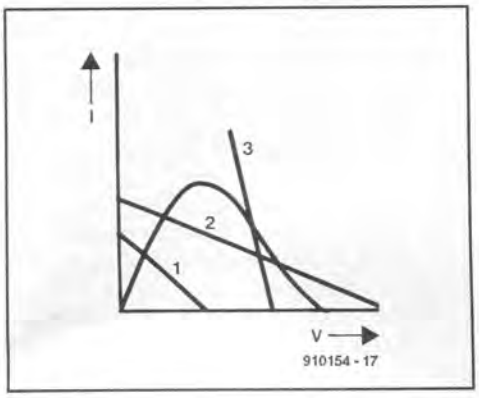


Fig. 7. Three possible load lines for the lambda diode: (1) monostable; (2) bistable; (3) oscillator.

bistable circuits. Which type of behaviour is exhibited depends on how the device is biased. Biasing is merely the term for setting up the circuit around a component so that it operates correctly, but note that negative dynamic resistance devices have several correct operating modes.

## Load lines

To determine how to bias a device, a simple graphical approach may be used. Take the example of a resistor and diode in Fig. 4. How can we calculate at what voltage the anode of the diode will run? If we plot the current-voltage behaviour of the diode, a curve like that in Fig. 6 would be obtained. If the diode were not in the circuit, the maximum voltage that could be present at the diode end of the resistor would be the supply voltage, $V_s$. If the diode were short-circuited, the maximum current that would flow would be $V_s/R$. These two values may be taken as the two ends of a line on the same graph. That line represents all the possible solutions to our problem. Since the diode must operate on its characteristic curve, too, the point at which the two curves intersect tells us (a) at what voltage and (b) at what current the anode of the diode will be. These lines are known as load lines.

So, by drawing the load lines, we may determine what are the operating points of any circuit. This is very simple in the case of the diode. Regardless of where we draw the load line of the resistor, it will intersect the characteristic curve of the diode in only one place. Note, however, that in the case of a tunnel diode or other device demonstrating negative resistance, there are several possible characteristics.

## The lambda diode

While tunnel diodes are relatively rare, *n*–channel and *p*–channel FETs are common. By combining an *n*–channel and a *p*–channel FET as shown in Fig. 5, a negative resistance device is formed. It is called the lambda diode, because its characteristic curve—see Fig. 6—looks like the Greek upper case lambda, Λ.

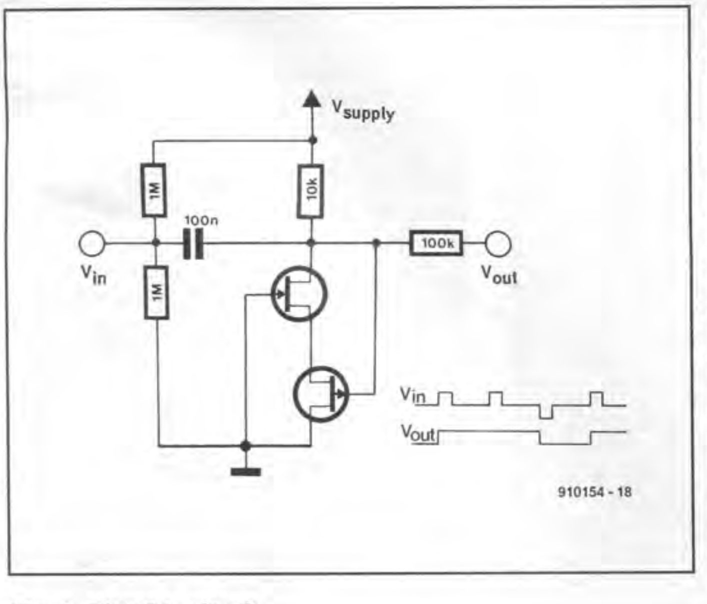


Fig. 8. Bistable circuit.

Figure 7 shows three possible biasing schemes for the lambda diode. In the first, the device has only one intersection or operating point. Despite any perturbations, the simple resistor and lambda diode combination will settle down to operate around this point: its point of stability.

In the second case, there are two points of stability: that is, the combination will work as a bistable. If it is at the lower-voltage point, momentarily increasing the voltage (for instance, by a pulse fed via a capacitor—see Fig. 8) will cause the circuit to stabilize at a higher voltage point. By applying a pulse in the opposite sense, the circuit will switch back to the first operating point: it is a bistable.

In the third case, there is only one operating point again but it is situated on the negative slope region of the characteristic curve. Here, given the right circumstances, the circuit may be made to oscillate. If a pulse is applied to the resonant *LC* circuit, the circuit will ring at a frequency given by

$$f = 1/2\pi\sqrt{LC},$$

where *f* is in Hz, *L* in H and *C* in F.

In an ordinary circuit, the resistance in the circuit causes the energy of the oscillations to be lost and the circuit ceases to oscillate. But if the resistance is countered by a negative resistance, the circuit will resonate indefinitely.

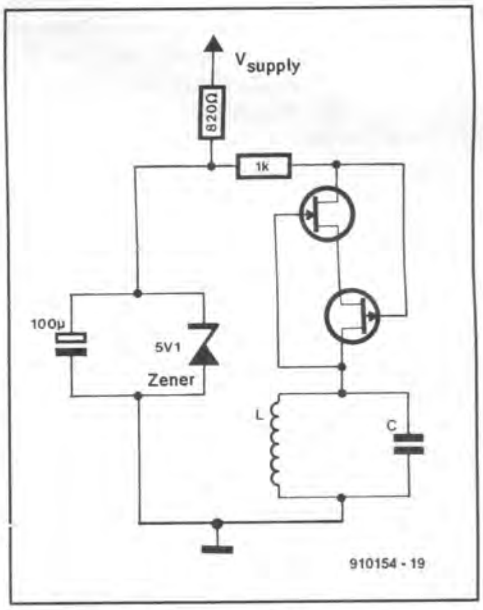


Fig. 9. Simple *LC* oscillator.

Figure 9 shows a suitable circuit for experimentation: $V_{s(upply)}$ is in all cases 12 V. The circuit tends to be very stable: typically, the drift is ≤100 p.p.m. per hour. The amplitude of the oscillations is about ±2 V. The output of the oscillator in any practical applications must be buffered, otherwise the load caused by the following circuitry represents additional resistance. As the power of the circuit is limited by the peak current that the lambda can draw (typically a few mA), a buffer stage is invariably required.

When the tuning capacitor is shunted by a varactor diode, the circuit may be tuned electronically. Note that the circuit is simplified by having only one tuning capacitor and a single, tap-less inductor, unlike the classical Hartley and Colpitts oscillators. ■

# PROTOTYPING BOARD FOR IBM PCs

**The insertion card described here enables you to build, quickly and easily, extension circuits intended to stay inside an IBM PC or compatible.**

**by A. Rigby**

A prototyping card is an essential item if you want to equip your PC with a new feature, say, a sound generator, a voice synthesizer, or a relay driver card, which is as yet in the development phase. Although prototyping cards for the PC are available ready-made from PC hardware suppliers, they are pretty expensive. As regards the choice of the interface to which the prototyping board is connected, the extension bus of the PC is the only viable alternative. Adequate as they are for their specific applications, the other interfaces, the parallel printer ports and the serial ports, are not really suitable for prototyping purposes, if at all they are 'free'. The prototyping card described here is, therefore, designed as an insertion card for the internal bus of the PC.

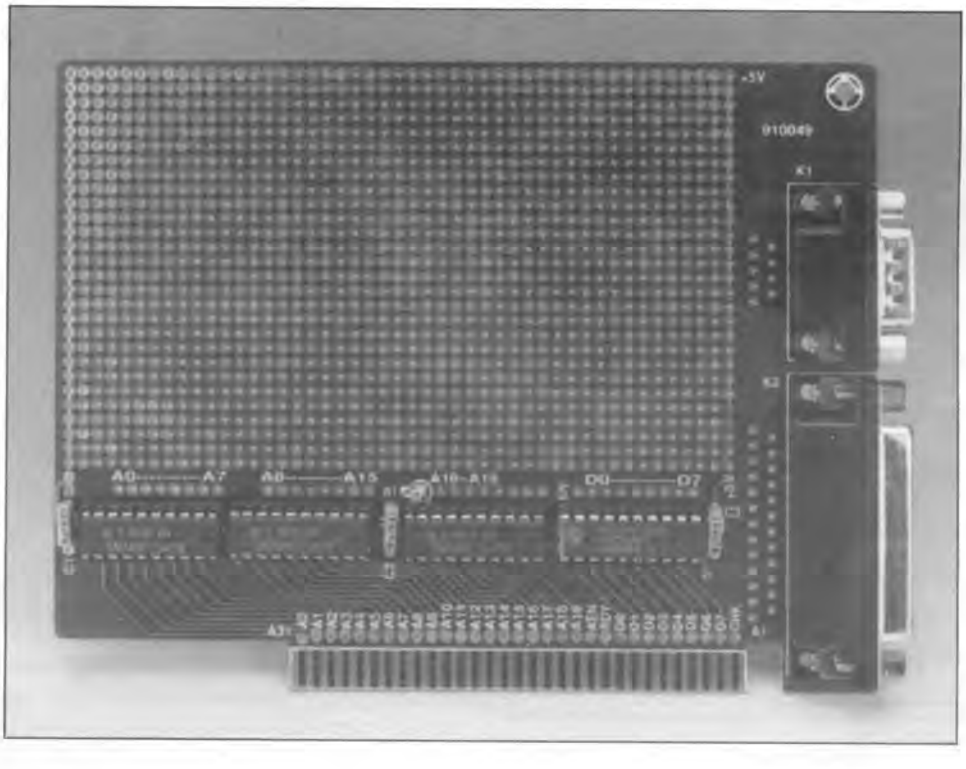
## The circuit

The circuit diagram of the prototyping board, Fig. 1, is really not more than a couple of buffer devices that serve to protect both the PC hardware and the circuit under development. Address decoding is not implemented here—this function has be provided by the circuit you wish to develop. In most cases, the address area reserved for prototyping boards will be used. According to the address assignment drawn up by IBM (see Table 2), prototyping cards must be located between $300_H$ and $31F_H$ in PC XTs and ATs.

Returning to the circuit diagram, the contact fingers on the board that connect to the PC bus extension slot are shown at the left as rows A and B. The card is equally suitable for 8-bit and 16-bit slots.

At the top of the diagram we find the databus buffer, IC4, whose direction (DIR) input is controlled by the buffered $\overline{\text{IORD}}$ signal supplied via buffer IC3. The logic level of the $\overline{\text{IORD}}$ line indicates whether the PC performs a read or a write operation. The enable ($\overline{\text{G}}$) input of the databus buffer is pulled to +5 V by resistor R1, and may be driven by the prototype circuit.

The address bus of the PC is buffered by IC1 and IC2, and four buffers contained in IC3. These three ICs are Type 74HCT541 octal non-inverting buffers with three-state outputs. Their outputs may be used to drive an address decoder in the prototype circuit. All three ICs have their enable inputs, $\overline{\text{G1}}$ and $\overline{\text{G2}}$, tied to ground, so that they are permanently enabled.



## Bus signals

The pin functions of the 8-bit extension slot connector in IBM PCs and compatibles are given in Table 1. A number of the signals available on this connector are of special interest, and described below.

**OSC** (pin B30) carries the clock signal of the I/O bus. The standard frequencies are 4.77 MHz in XTs, and 14.318 MHz in ATs. The mark/space ratio of this clock signal is 1:1.

**CLK** (pin B20) carries the system clock signal, which in the standard IBM PC is one third of the oscillator frequency, i.e., 1.59 MHz (4.77 MHz/3). The mark/space ratio of this signal is 1:2. It should be noted that the OSC and CLK frequencies used in today's PCs are much higher than those in the original IBM PC XT.

**RESET** (pin B02) serves to initialize the system when the power is switched on, or after a 'hang up' or hardware reset.

**$\overline{\text{IOWR}}$** (pin B13) is supplied by the bus controller, usually a Type 8288, and serves to indicate memory write operations.

**$\overline{\text{IORD}}$** (pin B14) is also supplied by the bus controller, and serves to indicate memory read operations.

**$\overline{\text{MEMRD}}$** (pin B12) indicates read operations by the processor or the DMA controller.

**$\overline{\text{MEMWR}}$** (pin B11) indicates that the data on the databus can be written to the location addressed by address lines A0 to A19.

The first thing to design into any circuit to be built on the prototyping card is a decoder that ensures proper addressing in the range reserved for the application. Figure 2 shows a simple address decoder based on a word comparator IC, the 74HCT688. All that is required to actually use this circuit is to set the switches in the DIL switch block to the required address, and connect the $\overline{\text{SELECT}}$ output to the EN input of the databus buffer in the PC interface, IC4. The address comparator uses 'full' I/O access decoding by making use of a logic combination (in an AND and an OR gate) of the AEN (address enable), $\overline{\text{IORD}}$ and $\overline{\text{IOWR}}$ signals, the latter two being supplied via buffers in IC3. The $\overline{\text{SELECT}}$ input goes low when the address preset on the switch block matches that supplied by the PC.

Finally, note that the memory area reserved for prototype card is relatively

| Signal name | Pin designation | | | Signal name |
|---|---|---|---|---|
| | track side | | compo-nent side | |
| GND | B01 | | A01 | $\overline{\text{I/O CHCK}}$ |
| RESET | B02 | | A02 | D7 |
| +5V | B03 | | A03 | D6 |
| IRQ2 | B04 | | A04 | D5 |
| –5V | B05 | | A05 | D4 |
| DREQ2 | B06 | | A06 | D3 |
| +12V | B07 | | A07 | D2 |
| reserved | B08 | | A08 | D1 |
| +12V | B09 | | A09 | D0 |
| GND | B10 | | A10 | I/O CHRDY |
| $\overline{\text{MEMW}}$ | B11 | | A11 | AEN |
| $\overline{\text{MEMR}}$ | B12 | | A12 | A19 |
| $\overline{\text{IOWC}}$ | B13 | | A13 | A18 |
| $\overline{\text{IORC}}$ | B14 | | A14 | A17 |
| $\overline{\text{DACK3}}$ | B15 | | A15 | A16 |
| DREQ3 | B16 | | A16 | A15 |
| $\overline{\text{DACK1}}$ | B17 | | A17 | A14 |
| DREQ1 | B18 | | A18 | A13 |
| $\overline{\text{DACK0}}$ | B19 | | A19 | A12 |
| CLK | B20 | | A20 | A11 |
| IRQ7 | B21 | | A21 | A10 |
| IRQ6 | B22 | | A22 | A9 |
| IRQ5 | B23 | | A23 | A8 |
| IRQ4 | B24 | | A24 | A7 |
| IRQ3 | B25 | | A25 | A6 |
| $\overline{\text{DACK2}}$ | B26 | | A26 | A5 |
| TC | B27 | | A27 | A6 |
| ALE | B28 | | A28 | A3 |
| +5V | B29 | | A29 | A2 |
| OSC | B30 | | A30 | A1 |
| GND | B31 | | A31 | A0 |

Table 1. Pinning of 8-bit bus extension slot.

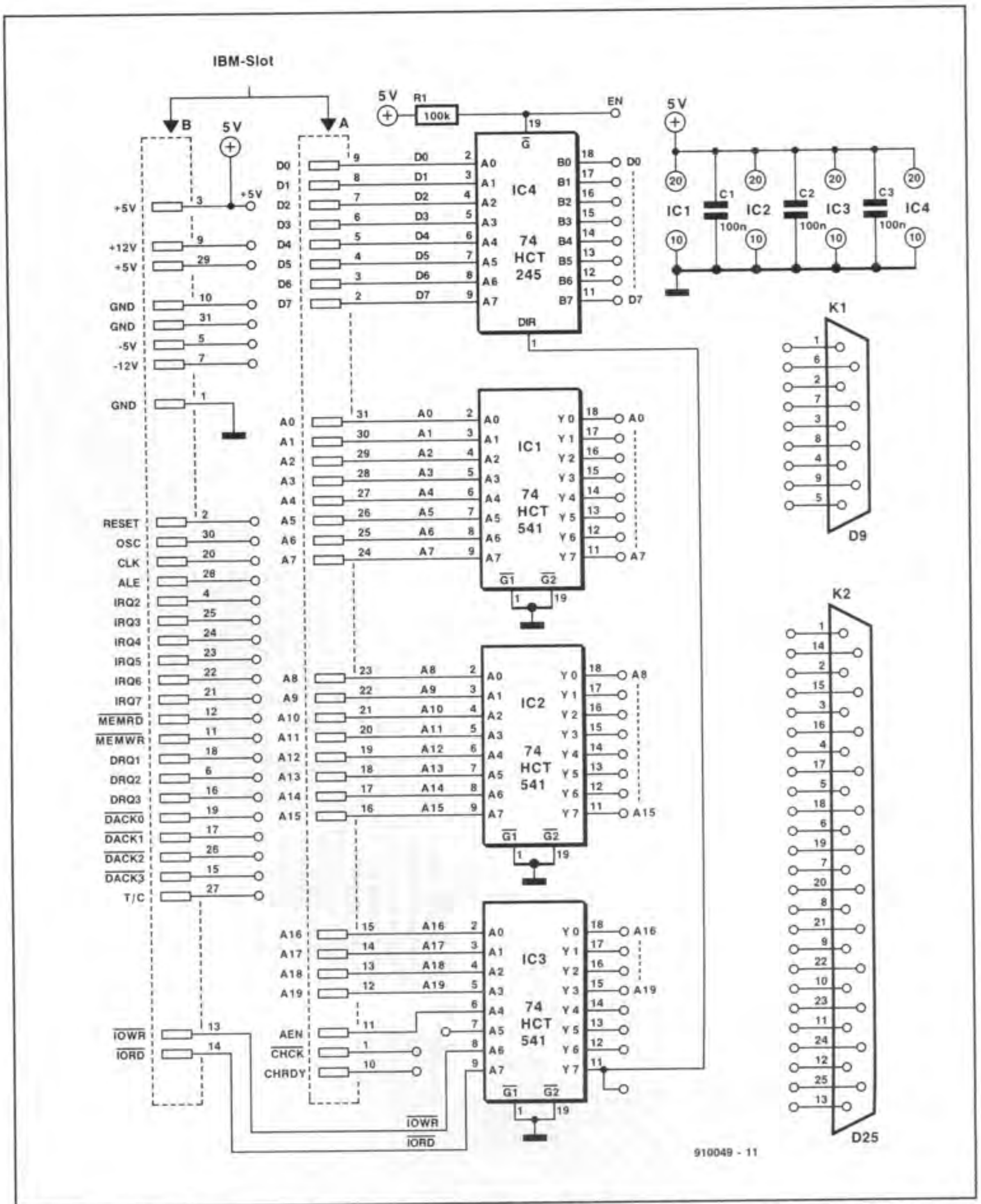


Fig. 1. Circuit diagram of the prototyping card. The ICs serve to prevent overloading of the PC's data lines, address lines, and a number of control lines.

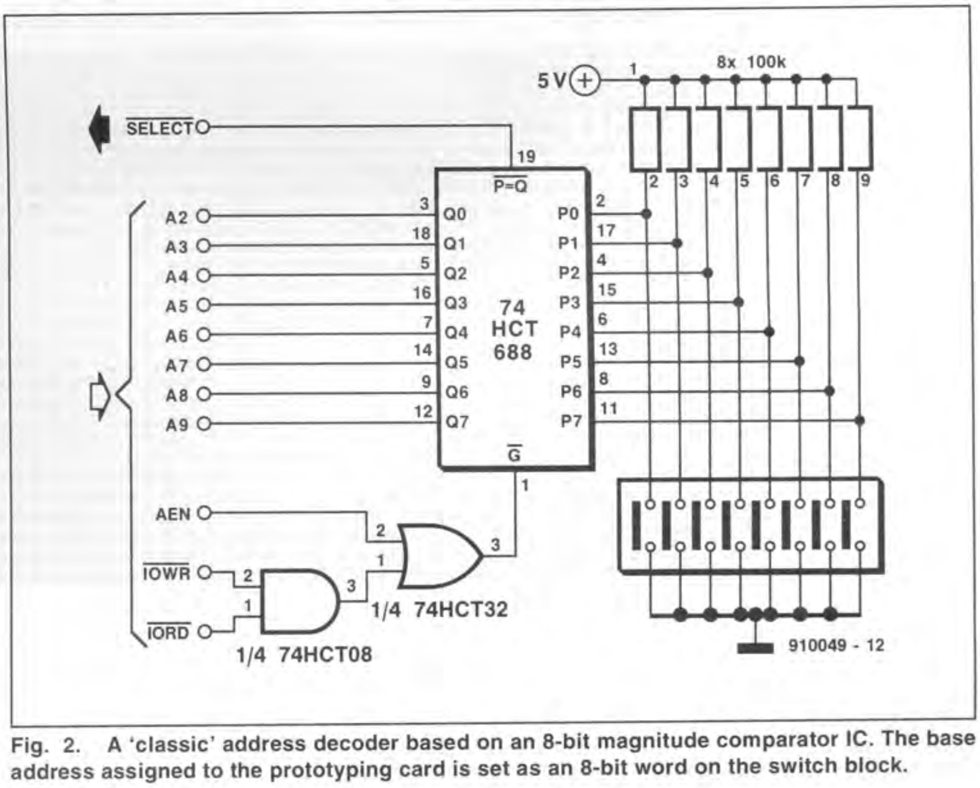


Fig. 2. A 'classic' address decoder based on an 8-bit magnitude comparator IC. The base address assigned to the prototyping card is set as an 8-bit word on the switch block.

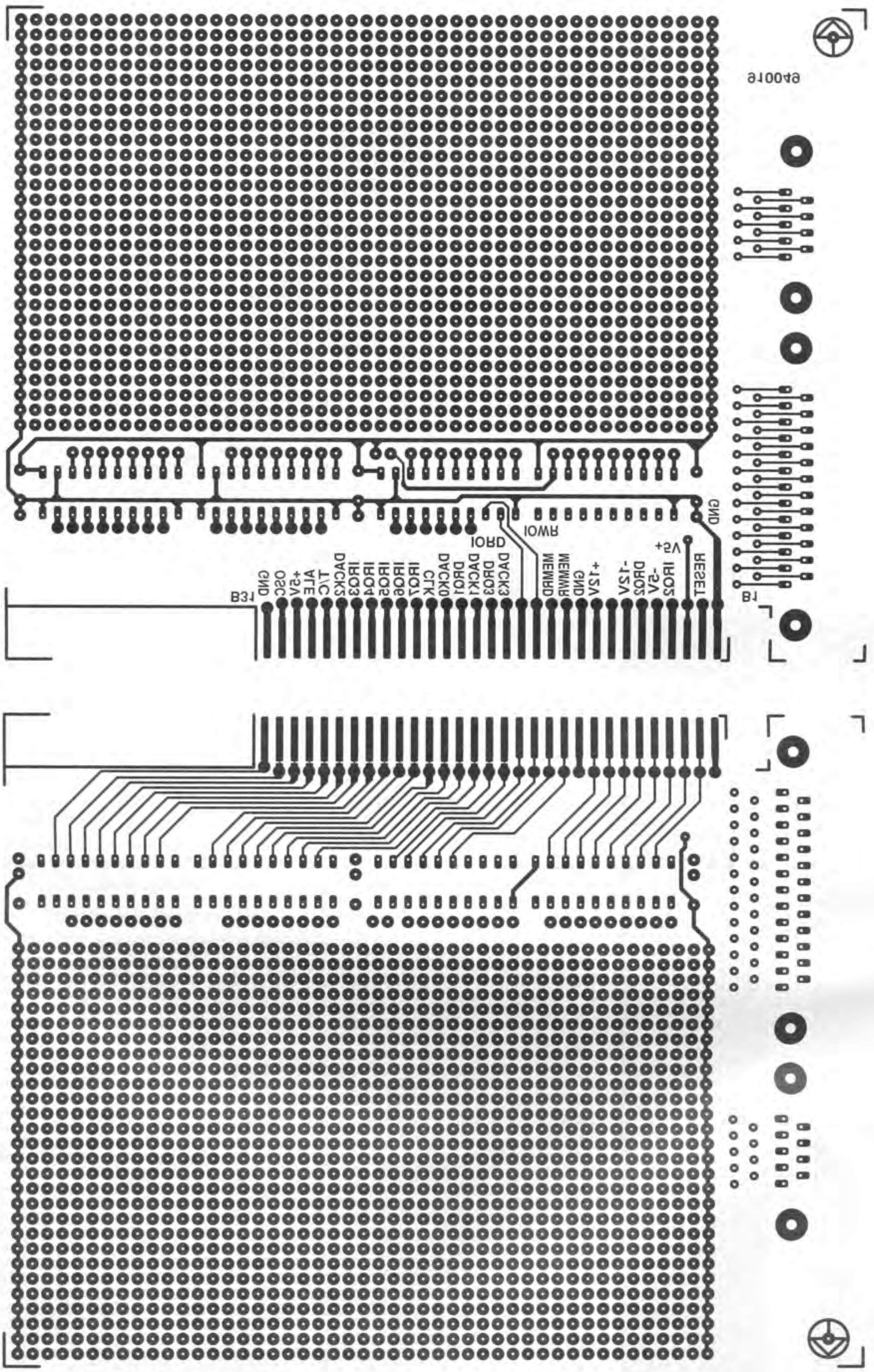
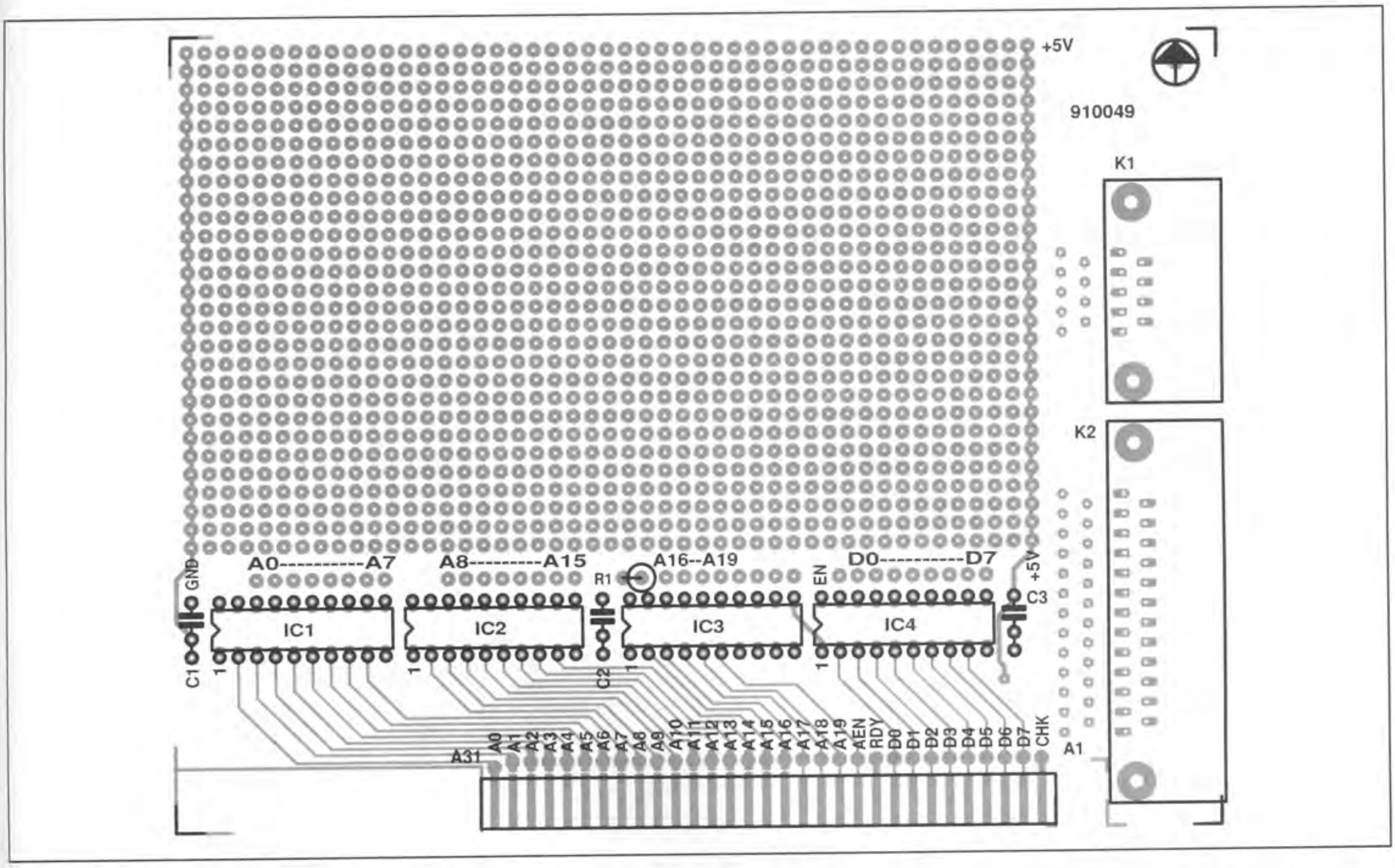


Fig. 3. Track layouts (mirror images) of the double-sided PCB.


+5V
910049
K1
K2
A1
A31
A0----------A7
A8---------A15
A16--A19
D0----------D7
R1
GND
EN
+5V
C1
C2
C3
IC1
IC2
IC3
IC4
1
A0 A1 A2 A3 A4 A5 A6 A7 A8 A9 A10 A11 A12 A13 A14 A15 A16 A17 A18 A19 AEN RDY D0 D1 D2 D3 D4 D5 D6 D7 CHK

| I/O Address | Function |
|---|---|
| $000_H$–$00F_H$ | DMA-Controller (8237A-5) |
| $020_H$–$021_H$ | Interrupt-Controller (8259-5) |
| $040_H$–$043_H$ | Timer/Counter (8253-5) |
| $060_H$–$063_H$ | System Register (8255A-5) |
| $080_H$–$083_H$ | DMA-Side Register (74LS670) |
| $0A0_H$–$0BF_H$ | NMI-Interrupt Register |
| $0C0_H$–$0FF_H$ | Reserved |
| $100_H$–$1FF_H$ | Front Panel Controller |
| $200_H$–$20F_H$ | For Computer Games (Game Port) |
| $210_H$–$217_H$ | Additional Unit |
| $220_H$–$24F_H$ | Reserved |
| $278_H$–$27F_H$ | Second Printer |
| $2F8_H$–$2FF_H$ | Second Serial Interface |
| $300_H$–$31F_H$ | Prototype Card |
| $320_H$–$32F_H$ | Hard Disk-Controller |
| $378_H$–$37F_H$ | Printer Interface (parallel) |
| $380_H$–$38F_H$ | SDLC-Interface |
| $3A0_H$–$3AF_H$ | Reserved |
| $3B0_H$–$3BF_H$ | Monochrome Adaptor and printer |
| $3C0_H$–$3CF_H$ | Reserved |
| $3D0_H$–$3DF_H$ | Colour Graphics Card |
| $3E0_H$–$3E7_H$ | Reserved |
| $3F0_H$–$3F7_H$ | Floppy Controller |
| $3F8_H$–$3FF_H$ | Serial Interface |

**Table 2. I/O address assignment in IBM PCs (source: IBM).**

## COMPONENTS LIST

**Resistors:**

| | | |
|---|---|---|
| 1 | 100kΩ | R1 |

**Capacitors:**

| | | |
|---|---|---|
| 3 | 100nF | C1;C2;C3 |

**Semiconductors:**

| | | |
|---|---|---|
| 3 | 74HCT541 | IC1;IC2;IC3 |
| 1 | 74HCT245 | IC4 |

**Miscellaneous:**

| | | |
|---|---|---|
| 1 | PCB-mount 25-way male sub-D connector | K1 |
| 1 | PCB-mount 9-way male sub-D connector | K2 |
| 1 | Printed circuit board | 910049 |

small, and located between $300_H$ and $31F_H$, which provides only 16 addresses.

## The printed circuit board

This consists of three sections:

- a section containing the address and data bus buffers;
- a section for prototyping;
- a section containing the output connectors.

The buffers are located close to the contact fingers on the board that plug into the PC extension slot. Provision is made for a number of tracks that carry the address lines A0 to A16 to be 'broken'. This option is provided because it will seldom be necessary to use all address lines. Where some of these are not required, the buffers associated with them are thus made available for other uses.

The prototyping area contains no fewer than 1316 solder pads arranged in 28 'columns' of 47 pads each. The pads in the left-hand column are interconnected and form a ground line. They are connected to pin B01, the system ground, on the extension slot. The right-hand column similarly forms the +5 V rail for prototype circuits, and is connected to extension slot pin B03.

The prototyping card provides two output plugs: a 25-pin and a 9-pin sub-D type, K2 and K1 respectively. These PCB-style plugs allow the circuit built in the prototyping area to be connected to the outside world. Each plug has a staggered row of solder pads to facilitate the soldering of wires.

## Construction

The prototyping board is simple to build, and the PCB (Fig. 3) is available ready-made through the Readers Services. As regards construction, all you have to do is consult the parts list and fit the components by reference number on to the card. Whether or not the sub-D plugs are mounted will depend on your application.

Now it is your turn to develop circuits that can be built in the prototyping area of the card. Suggestions abound: a speech synthesizer, a sound generator, a signal processor, etc.

Finally, when in doubt about the pinning of whatever connector, slot, cable or plug in your PC, consult the 'PC Connectors' wall chart supplied with the September 1991 issue of *Elektor Electronics*. ■

# UNIVERSAL RC5-CODE INFRA-RED RECEIVER

**This compact receiver is compatible with all infra-red remote controls that transmit RC5 codes. The RC5 set comprises 2,048 possible codes, all of which can be decoded and output by the present receiver. At the transmitter side, it is best to use a ready-made RC5 compatible infra-red remote control, an item that is available in many different versions as a spare part.**

**by A. Rigby**

REMOTE control these days seems commonplace for domestic audio/video equipment, and not a few electronics enthusiasts rightly wonder why it seems so difficult to implement on home-made projects.

The RC5 code is one of many systems developed by manufacturers of consumer electronics to standardize the control of their audio/video equipment. Most equipment produced with infra-red remote control uses a subset of RC5 codes. The universal character of the RC5 code set makes it particularly suited to home-made equipment.

Since the transmitter must be small, easy to operate, and its constituent parts cost about as much as the manufactured unit, it is best to buy one ready made.

## The circuit

The RC5 receiver is a relatively simple circuit—see Fig. 1. The functions of receiving and decoding the infra-red signal are handled separately by two integrated circuits. IC1 receives the infra-red signal via diode D1, and converts it into a TTL-compatible pulse train. The response of IC2 to this pulse train depends on the setting of the jumpers on the board. Assuming that jumpers S and A are fitted, the reception of an RC5 code will cause a command code to appear on lines D0–D5, and a system address on lines A0–A4. Also, the TO (toggle) line, pin 18, changes state. Testing this bit allows the receiver to detect the reception of a new code. Decoded data remains 'frozen' on the output lines until TO toggles.

If jumper A is removed, IC2 sees lines A0–A4 as inputs, on which the system address may be set. In this mode, the decoder will only accept command codes and feed these to outputs D0–D5 if the received code contains the set system address. This address is set with the aid of wire links on the printed-circuit board. A closed wire link represents a logic 0; an open wire link a logic 1. When all wire links are fitted, the system address is set to 'TV-set', or address 0. When no wire link is fitted, the address is within the range reserved for future extensions.

In both of the modes described above, the toggle bit changes once only, when the code is received correctly for the first time. This means that we do not know how long a key has been pressed on the transmitter. However, when jumper R (repeat) is fitted instead of jumper S (single), and jumper A is not fitted, bistable IC3b will change the toggle bit at a rate of 0.5 s while a transmitter key is pressed.

IC3b is wired as a monostable multivibrator (MMV), and clocked repeatedly by the $\overline{\text{RECVD}}$ output of IC2. Unlike the TO output, the $\overline{\text{RECVD}}$ output supplies a pulse train while a transmitter key is pressed. When the clock pulse is received at pin 3, the Q output of IC3b goes high. This in turn clocks IC3a which divides by two and serves as the toggle bistable. If more pulses follow after the first clock pulse, nothing changes during the first 0.5 s. After that, IC3b is reset because

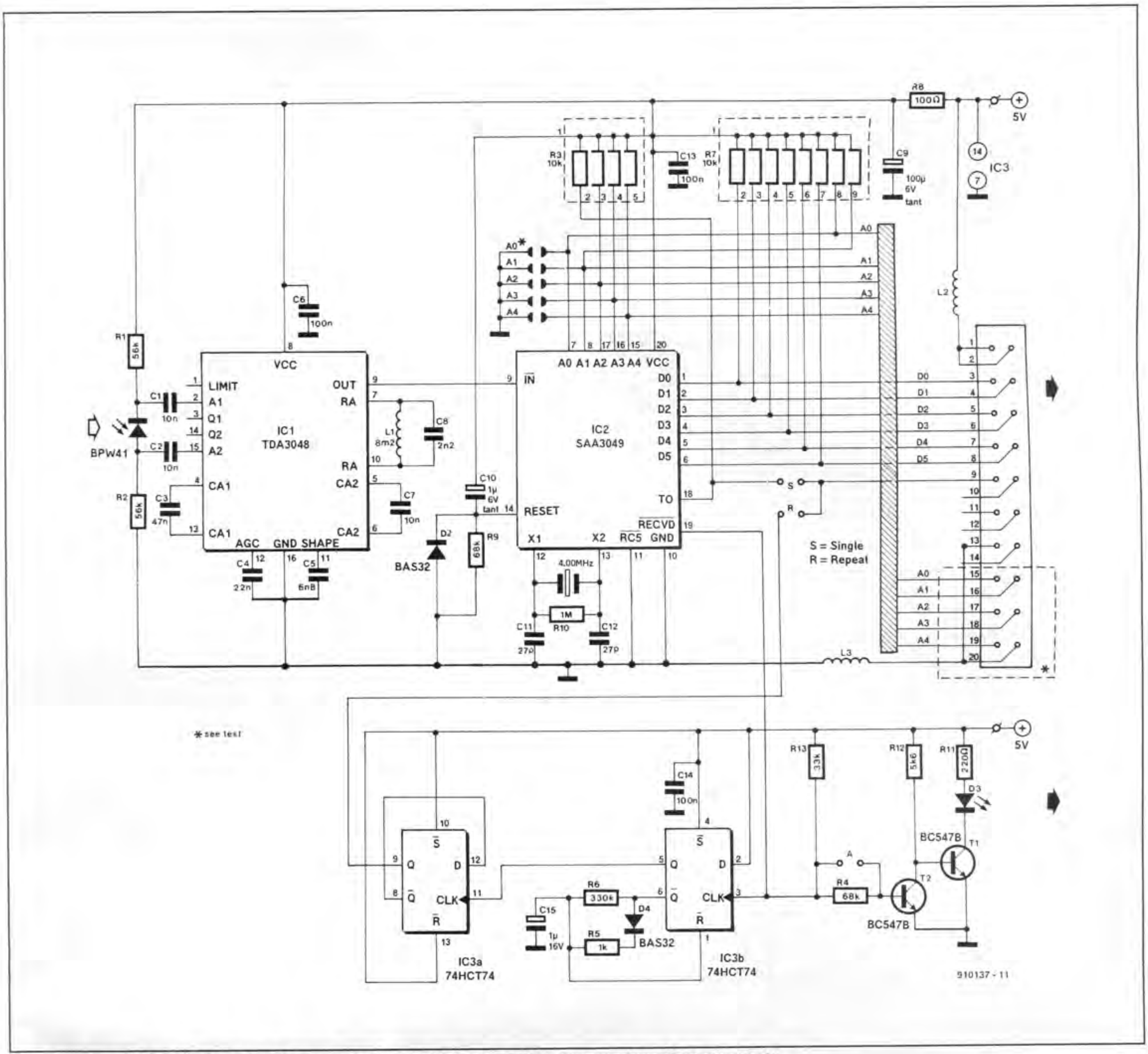


Fig. 1. **A sensitive RC5 code infra-red receiver built from a minimum number of components.**

C15 is discharged via R6. Consequently, the $\overline{Q}$ output goes high again, and C15 is charged rapidly via D4 and R5, which ends the reset state. At the next RECVD pulse, the Q output of IC3b changes to high again and clocks IC3a, which toggles. In this way, the toggle bit changes state every 0.5 s, as long as the receiver receives the code.

The above is possible only when the sub address is set via solder links A0–A4, which will be the most frequently used option. When it is desired to read the address also (jumper A fitted), the 'repeat' option may still be implemented if a small modification is made to the board: connect pin 3 of IC3 direct to the cathode of D3 (do not insert pin 3 of IC3 into the PCB hole while fitting the IC, and connect it to D3 via a short piece of wire).

The system address and the command code are fed to external equipment via connector K1. When the fixed system address option is used, a 14-way connector may be used for K1. If the system address is not fixed, the address lines must be brought out also, so that a 20-way connector is required.

The receiver is powered via connector K1. The circuit draws about 5 mA in the stand-by state. This current increases a little when an RC5 code is received, since LED D3 then lights. Inductors L2 and L3 are wound on a single core, and serve to suppress interference on the power supply rails. A clean supply voltage is necessary because the receiver operates with very low signal levels at its input. Hence, the cleaner the supply, the greater the maximum distance that can be covered by the remote control system.

## Construction

Figure 2 shows the printed-circuit designed for the RC5 receiver. The board holds a combination of SMA (surface-mount assembly) and traditional components. SMA components are used here for two reasons: first, to keep the size of the receiver as small as possible; and second, to ensure the shortest possible signal routes in the circuit, which helps to give the remote control the largest possible range. The PCB design shows clearly that IC1 is tailored to work with SMA components—nearly all components associated with this IC are conveniently fitted between its two pin rows.

Start the construction by placing, aligning and soldering all SMA parts. Always pre-tin one pad, solder the SMA part to it, and then solder the other side. It is best to use solder tin of a diameter of 0.8 mm (0.3 in) and a solder iron with a fine tip. The remainder of the components are fitted in the usual manner, starting with the low-profile parts.

Inductors L2 and L3 are home made as illustrated in Fig. 3: put two windings of 10 turns of 0.5-mm diameter (SWG18; AWG19) enamelled copper wire on to the ring core. Both inductors are wound in the same direction.

To isolate it completely from external

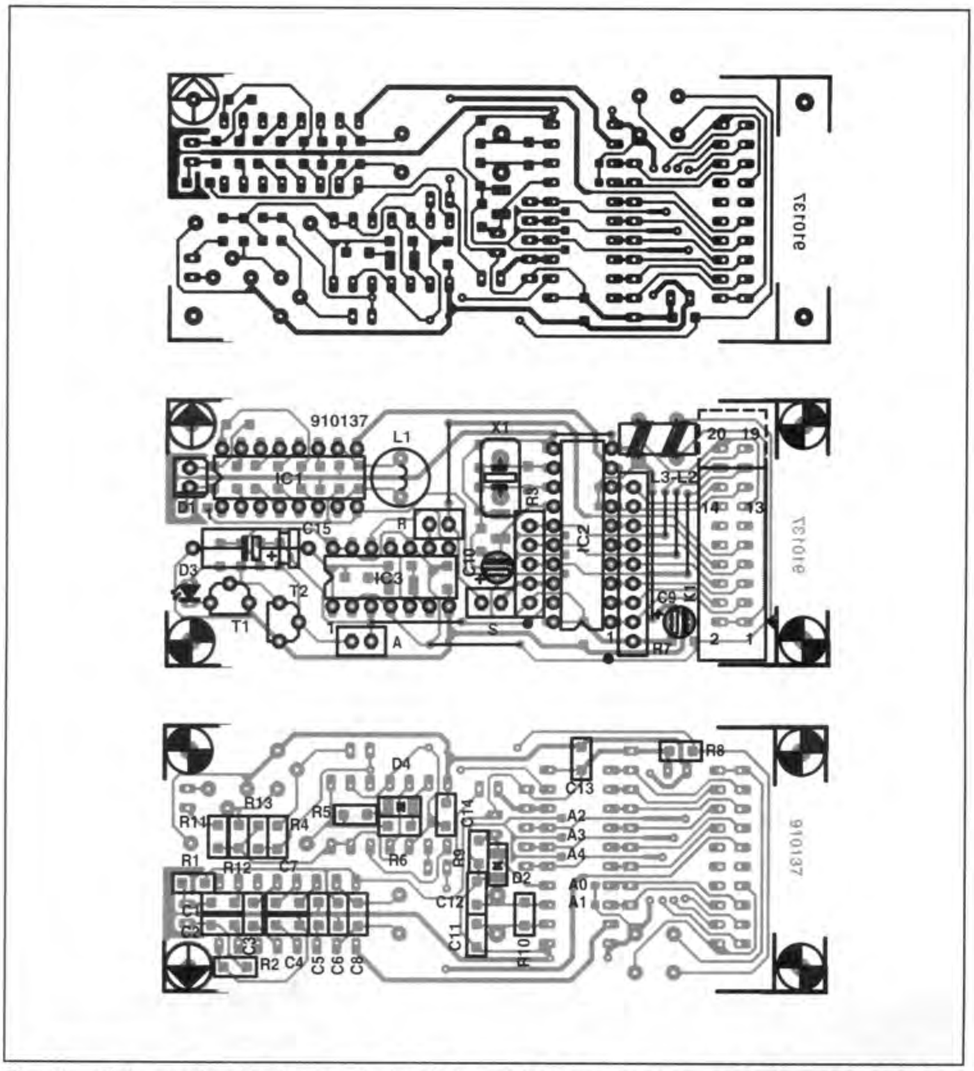


**Fig. 2. This single-sided printed circuit board has components at both sides—the SMA parts go to track side of the board.**

**Table 1. Jumper settings**

| | |
|---|---|
| **A open:** | single-system mode; a single address is hardwired to terminals A0–A4. |
| **A closed:** | combined-system mode; received system address is supplied via terminals A0–A4. |
| **S closed; R open:** | single mode; toggle output changes state on receipt of a new code only; |
| **S open; R closed:** | repeat mode; toggle output changes state every 0.5 s as long as a code is received. |

## COMPONENTS LIST

**Resistors:**

(all SMA except R3 and R7)

| | | |
|---|---|---|
| 2 | 56kΩ | R1;R2 |
| 1 | 4-way 10kΩ SIL (normal size) | R3 |
| 2 | 68kΩ | R4;R9 |
| 1 | 1kΩ | R5 |
| 1 | 330kΩ | R6 |
| 1 | 8-way 10kΩ SIL (normal size) | R7 |
| 1 | 100Ω | R8 |
| 1 | 1MΩ | R10 |
| 1 | 220Ω | R11 |
| 1 | 5kΩ6 | R12 |
| 1 | 33kΩ | R13 |

**Capacitors:**

(all SMA, except electrolytic caps)

| | | |
|---|---|---|
| 3 | 10nF | C1;C2;C7 |
| 1 | 47nF | C3 |
| 1 | 22nF | C4 |
| 1 | 6nF8 | C5 |
| 3 | 100nF | C6;C13;C14 |
| 1 | 2nF2 | C8 |
| 1 | 100µF 6V tantalum | C9 |
| 1 | 1µF 6V tantalum | C10 |
| 2 | 27pF | C11;C12 |
| 1 | 1µF 16V axial | C15 |

**Inductors:**

| | | |
|---|---|---|
| 1 | choke 8mH2 | L1 |
| 1 | 1-cm dia. ferrite ring core e.g., T37-6 (see text) | L2;L3 |

0.5-mm dia (18SWG; 19AWG) enamelled copper wire

**Semiconductors:**

| | | |
|---|---|---|
| 1 | BPW41 | D1 |
| 2 | BAS32 (SMA) | D2;D4 |
| 1 | LED | D3 |
| 2 | BC547B | T1;T2 |
| 1 | TDA3048 | IC1 |
| 1 | SAA3049 | IC2 |
| 1 | 74HCT74 | IC3 |

**Miscellaneous:**

| | | |
|---|---|---|
| 3 | 2-way pin header and jumper | A;S;R |
| 1 | 14-way or 20-way box header | K1 |
| 1 | 4-MHz quartz crystal | X1 |
| 1 | Printed circuit board | 910137 |

(stray) radiation, the receiver may be enclosed in a box made of thin sheet metal. The metal is fixed to solder pins at the corners of the board. This construction provides a ground connection where the IR diode is fitted.

## The transmitter

Although this article is not concerned with the building of an IR transmitter, it is, none the less, useful to understand its operation. In most cases, the system address sent by the transmitter will have to be changed. A logical choice for the system address is one of the addresses reserved for experimental purposes: 7 or 19.

Most infra-red remote control transmitters are downright simple circuits, as illustrated in Fig. 4. One IC does all the work, and this is usually one of three SAA or SAF types that are pin-compatible with very small differences.

Here, only pin 2 (SSM) and the two keyboard matrices are of interest. The X/DR-matrix contains the push-buttons that serve to transmit certain command codes. The number with a push-button indicates the corresponding code.

The Z/DR matrix serves to indicate the system address to be transmitted along with the command code. The numbers adjacent to the keys are the corresponding system addresses. The logic level applied to pin 2 of the IR transmitter IC determines whether the Z/DR-matrix actually consists of keys, or is

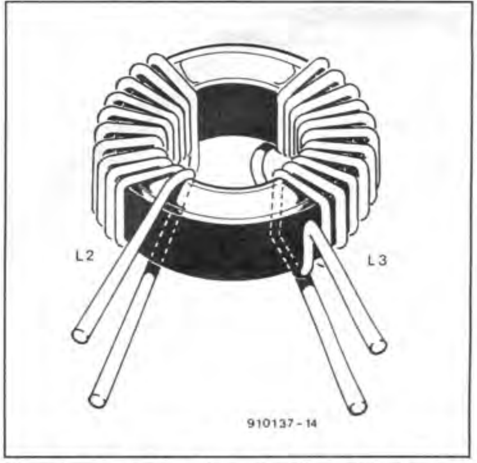
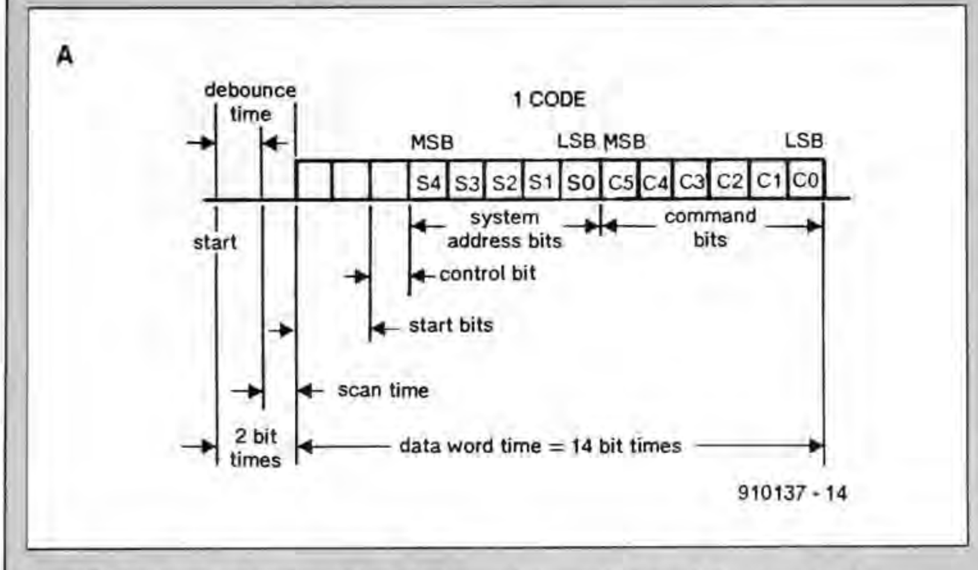


**Fig. 3. Construction details of inductors L2 and L3.**

# BACKGROUND TO THE RC5 CODE



The RC5 code set developed by Philips allows 2,048 commands to be transmitted, divided into 32 addressable groups of 64 commands each. In this system, each piece of equipment is assigned its own address, so that, for example, a volume setting command is not processed by a TV set and a preamplifier at the same time. The RC5 code set is extended and updated as new equipment is introduced, for instance, the new DCC (digital compact cassette) recorder.

The transmitted code consists of a 14-bit dataword of the following structure:

- 2 run-in bits to adjust the AGC (automatic gain control) level in the receiver IC;
- 1 check bit that indicates a new data transfer (order: MSB first);
- 6 bits that indicate the command (MSB first).

This structure is illustrated in Fig. A. To prevent interference from other infra-red sources (e.g., incandescent lamps), the code is transmitted in biphase format. In this system, a logic 1 is transmitted as a half bit time without signal, followed by a half bit time with signal. A logic 0 has exactly the opposite structure: a half bit time with signal followed by a half bit time without signal. Figure B shows the structure. Each half bit consists of 32 shorter pulses.

Each transmitted bit has a length of 1.778 ms—this time is derived from a 36-kHz oscillator. The frequency is chosen to prevent interference with, among other sources, wireless headphones and horizontal deflection circuits in TVs.

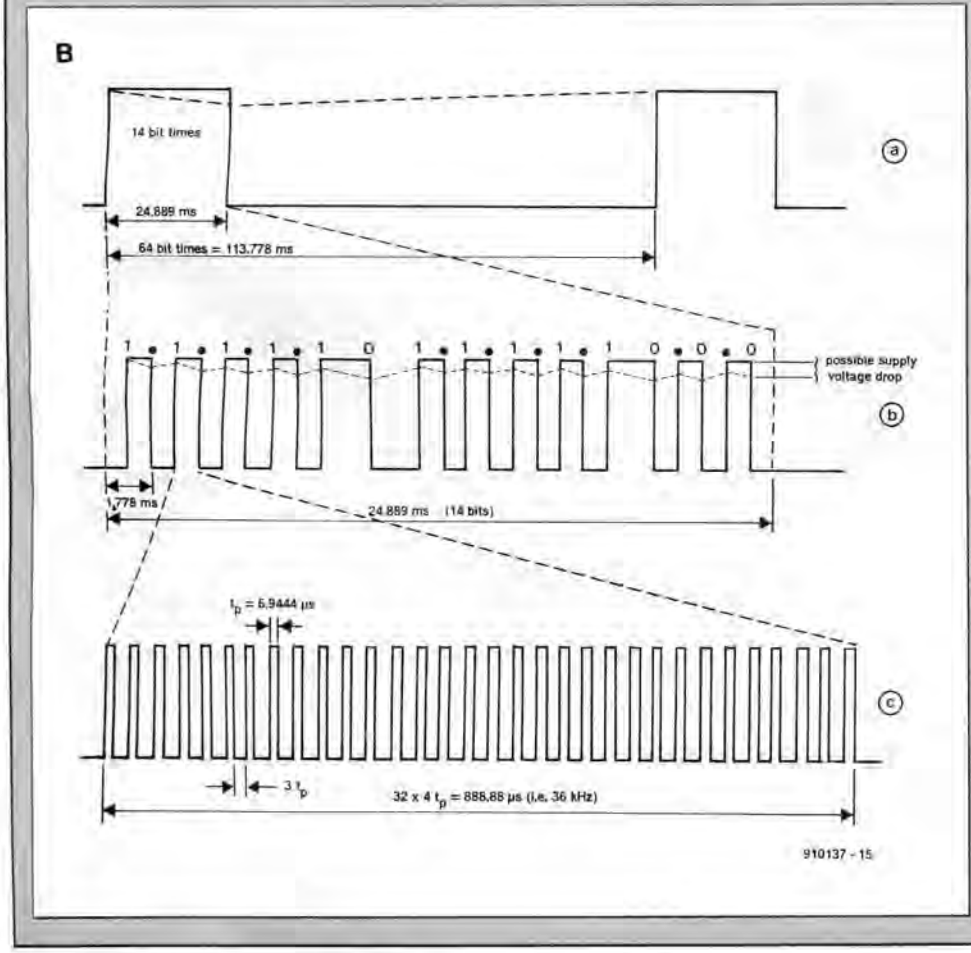
A complete dataword has a length of 24.889 ms, and is always transmitted complete, even if the relevant key is released within this period. If the key is held pressed, the associated dataword is repeated in intervals of 64 bit times (i.e., 113.778 ms).

The tables provide the most essential information to enable home-made equipment to be controlled via an existing RC5-compatible remote control. The two addresses reserved for experimental applications are of particular interest. In all cases, the IR transmitter must be set to the address assigned to the equipment to be controlled.

**RC5 code address/command overview**

| System address | Equipment |
|---|---|
| 0 | TV set |
| 2 | Teletext |
| 5 | video recorder |
| 7 | experimental |
| 16 | preamplifier |
| 17 | receiver/tuner |
| 18 | tape/cassette recorder |
| 19 | experimental |

| Command code | Function |
|---|---|
| 0–9 | 0–9 |
| 12 | stand-by |
| 13 | mute |
| 14 | presets |
| 16 | volume + |
| 17 | volume – |
| 18 | brightness + |
| 19 | brightness – |
| 20 | c. saturation + |
| 21 | c. saturation – |
| 22 | bass + |
| 23 | bass – |
| 24 | treble + |
| 25 | treble – |
| 26 | balance right |
| 27 | balance left |
| 48 | pause |
| 50 | fast reverse |
| 52 | fast forward |
| 53 | play |
| 54 | stop |
| 55 | record |



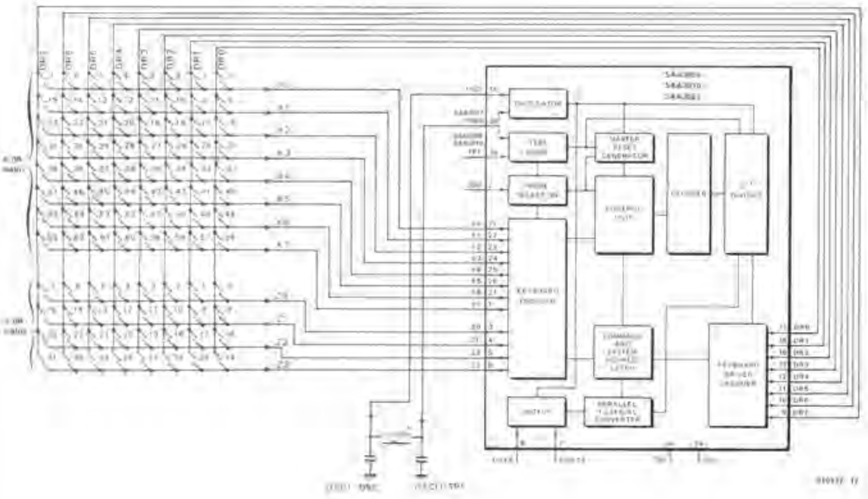


Fig. 4. Typical keyboard/IC configuration in an RC5-compatible infra-red remote control transmitter.

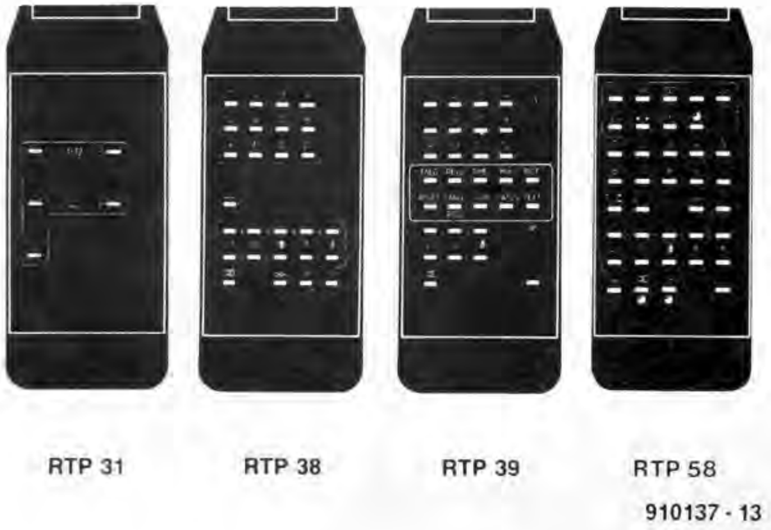


Fig. 5. A selection of particularly suitable Policom infra-red remote control boxes.

Fig. 6. Close-up of the connector side of the board.

formed by a single wire link. This option indicates whether the remote control is used in single system mode or in combined system mode.

When pin 2 is low, the transmitter operates in combined system mode, which means that the keys in the Z-matrix may be used to indicate the system address to be sent before the commands. This address is latched internally, so that the system key need not be kept pressed all the time. If a new system address is selected with the aid of a key in the Z-matrix, the transmitter will send this address together with command 63 ($111111_2$; system select). On receipt of this command, the selected (addressed) system 'wakes up'.

The operation of the transmitter IC in single-system mode (SSM) is practically the same as described above. In this mode, the Z-matrix consists of one fixed connection between a DR line and a Z line. Hence, the system address transmitted by the remote control box can be changed by removing this connection, and fitting another. This connection effectively forms a pressed key in the Z-matrix. Incidentally, there are also remote control boxes in which the IC is permanently wired to SSM mode, and still capable of addressing two different systems (e.g., a TV set and a video recorder) with the aid of a switch (or a set of electronic switches).

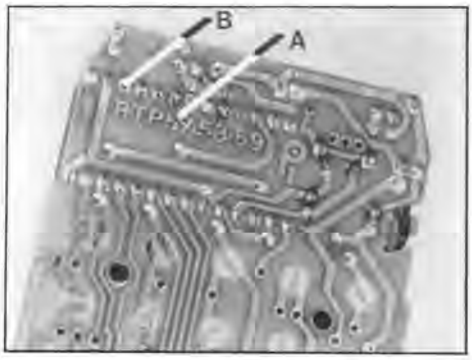


Fig. 7. Setting a new system address in a remote control transmitter.

Infra-red remote control transmitters using the RC5 code are available in various versions from a number of manufacturers and distributors of radio/TV spare parts. Figure 5 shows a number of types from the range produced by Policom. The choice between these types depends on the application you have in mind. In most cases, it is desirable that the functions available on the box correspond, or correspond largely, to those required for your particular application. All Policom transmitters have the advantage of being modified easily. For instance, you may want to design your own front panel lettering and key symbols, and stick this over the existing template on the flat controls panel.

In all cases, the box must be opened to change the system address. This is done by removing the screw in the battery compartment. The two halves of the case can them be separated by shifting them lengthwise. While doing this, keep the push-buttons down to prevent them dropping from the front panel. To change the system address, remove the connection between one of the Z lines and one of the DR lines. Note that this connection may not always be visible because of a double-sided printed circuit board. The connection may be broken by desoldering the pin of the relevant Z connection from the board. Next, the new address is set by fitting a wire. Figure 7 shows how the modification was carried out on the transmitter used for developing the receiver. ■

# READERS' CORNER

## LETTERS

### A simple watchdog circuit

Sir—In my article 'A simple watchdog circuit' (November 1991 - p. 45), a mistake has crept into the circuit diagram. Pin 1 of gate $IC_{1a}$ is shown connected to the supply voltage. This is not correct, because the output of the circuit would remain high forever. The simple remedy is, of course, to disconnect pin 1 from the +5 V supply line.

Akbar Afsoos, Isfahan, Iran.

### Wattmeter - April 1991

Sir—I refer to the letter by Mr Gene May and your comment to it in the September 1991 issue. I must confess to having also been sceptical about the phase angle question when abstracting the article. However, a little elementary analysis revealed that you have not been sold a 'Lemon'!

Mr May has missed the point that phase difference is preserved in the two sample voltages applied to the multiplier; also, that a fundamental property of four-quadrant multipliers is that phase difference is taken into account automatically with multiplication of instantaneous values.

I will quote the appropriate entry in the *Amateur Radio Technical Abstracts:*

'Wattmeter. J. Lemon, Elektor vol 17 no 188 April 1991 pp 32–35. An electronic AC wattmeter is described. It is based on the use of a Motorola MC1495L four-quadrant multiplier. A digital display is included. The instrument gives an accurate measurement of true power, regardless of the waveform or phase angle. (Editor's note – It is not spelt out in the article, but if voltages proportional to the instantaneous values of applied voltage and load current are multiplied, the product consists of a DC voltage together with an AC component. The DC component is directly proportional to true power, and is independent of waveform and frequency.)'

It is significant to note that the input to Mr Lemon's display circuit contains a low-pass filter. The mathematical basis for my conclusions is shown below.

I believe Mr Lemon deserves congratulations for his ingenious instrument. It is a significant contribution to electrical engineering.

Multiplier output =

$$
\begin{aligned}
&= k_1 E \sin\omega t \times k_2 I \sin(\omega t+\phi) \\
&= k_1 E \sin\omega t \times k_2 I[\sin\omega t\cos\phi+\cos\omega t\sin\phi] \\
&= k_3 EI[\sin^2\omega t\cos\phi+\sin\omega t\cos\omega t\sin\phi] \\
&= k_3 EI[\tfrac{1}{2}(1-\cos2\omega t)\cos\phi+\tfrac{1}{2}\sin2\omega t\sin\phi] \\
&= \tfrac{1}{2} k_3 EI[(1-\cos2\omega t)\cos\phi+\sin2\omega t\sin\phi] \\
&= \tfrac{1}{2} k_3 EI[\cos\phi-\cos2\omega t\cos\phi+\sin2\omega t\sin\phi] \\
&= \tfrac{1}{2} k_3 EI[\cos\phi-\{\tfrac{1}{2}\cos(2\omega t-\phi)+ \\
&\quad +\tfrac{1}{2}\cos(2\omega t+\phi)\}+\tfrac{1}{2}\cos(2\omega t-\phi)- \\
&\quad -\tfrac{1}{2}\cos(2\omega t+\phi)] \\
&= \tfrac{1}{2} k_3 EI[\cos\phi-\cos(2\omega t+\phi]
\end{aligned}
$$

$\therefore$ DC component = $\tfrac{1}{2} k_3 EI\cos\phi$,
that is, $\propto EI\cos\phi$ (true power).

Graham Thornton, VK3IY
Editor/publisher *Amateur Radio Technical Abstracts* (ISSN 1036-3025), P O Box 298, World Trade Centre, Melbourne 3005, Australia.

*Contrary to our normal policy of not publishing the address of correspondents, in this case we felt that many readers would be interested to learn of the Abstracts.* Ed.

APOLOGIES

In our November 1991 issue, the word 'biro' was used as a general term for a ballpen. We have been advised that this is an infringement of a registered trade mark: the name 'Biro' should be used only for pens made under that mark by Biro Bic Limited. We hereby unreservedly apologize for this oversight.

### 8032/8052 BASIC computer

Sir—Regarding the '8032/8052 BASIC computer' (May 1991 - pp. 17–23), here is a tip in which many readers may be interested.

The EPROM, a 27(C)256, which is a 32K by 8-bit device, is mapped in this particular circuit, dependent on the setting of jumper 'A', both at 0000H for 16K and 8000H for the other 16K of the memory. If the ROM is programmed or burnt with a program or even the BASIC interpreter, the 8052 will only address and program the EPROM from address 8000H. This puts the program in EPROM right in the middle of the EPROM's address space, or at EPROM address 4000H.

If it is required to dump the interpreter and program the EPROM, that should be done at its address 0000H so that the MPU can find the interpreter. In other words, if the lower address space in the EPROM is to be used, the EPROM's ability to be programmed on the system board at 8000H must be enabled, so that the programming will be written to the memory's address location 0000H, not 4000H.

Also, I note that the basic program listing in its byline states: ". . . type in this listing if you want to unload the BASIC interpreter from the 8052AH-BASIC CPU . . .'. The program disallows any address below 512 decimal. The interpreter and start-up code is located at address 0000H. The 8052 will not allow an EPROM address below 8000H, at least for EPROM programming (burning) purposes.

*Name and address withheld at the writer's request.* Ed.

## CORRECTIONS

### Measurement techniques - Part 7

(September 1991 - p.29)

On page 30, first column, the formula for calculating $C$ is given as

$C = 25{,}400 / Ff^2$ [pF].

This should, of course, have read

$C = 25{,}400 / Lf^2$ [pF].

### Buid the Opticalock - Part 1

(September 1991 - p. 42)

Diode $D_{10}$ is drawn with wrong polarity in the circuit diagram (Fig. 3, p. 44) and the PCB component side (Fig. 4, p. 45).